Volume 24 DECEMBER, 1940 Number 12

BULLETIN

of the

American Association *of* Petroleum Geologists

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BULLETIN

of the

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BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

DECEMBER, 1940

HEAVY-MINERAL ZONES OF LOUISIANA AND TEXAS GULF COAST SEDIMENTS[1]

WILLIAM M. COGEN[2]
Houston, Texas

ABSTRACT

The method of sample preparation and the procedure for examination of the heavy minerals under the petrographic microscope are briefly outlined.

The heavy-mineral assemblages characterizing five mineral zones in the subsurface Cenozoic formations of the Louisiana Gulf Coast are described and the variation in mineral assemblage which occurs with depth is illustrated by heavy-mineral well logs.

Heavy-mineral assemblages from outcropping Cenozoic formations in Texas and Louisiana are described and graphically illustrated.

Comparisons between the mineral assemblages in the formations at the outcrop and in the subsurface are made and interpreted. It is concluded that several distributive provinces of differing mineralogical composition contemporaneously contributed sediments to the coastal region. The data suggest that a substantial portion of the Cenozoic sediments in the subsurface of southern Louisiana was brought there not directly from the interior but from the east or west, or both directions, presumably by longshore currents.

It is demonstrated that mineral-zone boundaries may transect formations and paleontologic horizons. For example, the base of the Kyanite zone is shown to transgress from Eocene strata in the interior into Miocene post-*Discorbis* zone sediments near the coast.

INTRODUCTION

ACKNOWLEDGMENTS

This paper is a result of heavy-mineral studies which the Shell Oil Company, Incorporated (formerly Shell Petroleum Corporation) conducted for several years and which the writer pursued during 1937 and 1938. More than 2,000 samples were utilized for this investigation. Of this number about 1,000 were examined by the writer, the remainder by earlier investigators.

The reports of C. H. Edelman, D. J. Doeglas, C. W. Fulcher, and M. Bornhauser concerning heavy minerals of Gulf Coast formations were available to the writer in the files of the Shell Oil Company, and

[1] Read before the Society of Economic Paleontologists and Mineralogists at Chicago, April 12, 1940. Manuscript received, June 24, 1940.

[2] Shell Oil Company, Inc.

the conclusions reached by the writer were, without doubt, influenced by the views expressed in the reports of the aforementioned authors. However, these conclusions are founded on the writer's analysis of the accumulated data, and responsibility for them rests with him. To T. L. Bailey the writer is grateful for suggestions and criticisms accorded to him during numerous discussions of this study. The writer wishes also to express his appreciation to Donald Bell for the careful preparation of most of the samples used in this study.

METHODS OF SAMPLE PREPARATION AND EXAMINATION

The methods of sample preparation and mineral examination were, with minor variations, similar to those described by H. B. Milner.[3] Only cores were used for this study. The sample was disintegrated in water. Particles smaller than very fine sand (.05 mm.) were removed by allowing the agitated sediment to settle for 20 seconds, then decanting the supernatant suspension. The sample was treated successively with hydrochloric and nitric acid to remove carbonates and pyrite and to clean the minerals of iron stains. Following this treatment, the sediment was sieved through a ½-mm. mesh screen and the coarser material was discarded.

Bromoform, with a specific gravity of about 2.87, was used to separate the heavy from the light minerals. The heavy residue was mounted in Canada balsam on glass slides and examined under the petrographic microscope. One hundred non-opaque minerals randomly distributed through the heavy residue were identified and percentages of the various mineral species were thus counted and recorded.

GENERAL CHARACTERISTICS OF HEAVY-MINERAL ZONES

Several mineral zones of widespread occurrence have been recognized in the subsurface Cenozoic sediments of southern Louisiana. These zones are distinguished by qualitative differences in their mineral assemblages, that is, by differences of mineral species in the assemblages, rather than by quantitative variations in the relative proportions of the heavy minerals. Zones based on qualitative differences have been found to have a much wider extent in the Gulf Coast sediments than those based only on quantitative variations of the relative proportions of the minerals in the heavy residue. The latter are sometimes useful for local correlations.

Each mineral zone does not necessarily mark an accumulation of

[3] H. B. Milner, *Sedimentary Petrography*, 2nd edition (1929).

sediment derived from some one distributive province. Many zones possess a composite mineral assemblage derived from two or more provinces that, perhaps, were widely separated but which drained into the same basin of deposition and each of which was characterized by a distinctive mineral assemblage. It is not uncommon for a zone to possess a mineral assemblage which is a composite of the suite characterizing the underlying contiguous zone and of another mineral assemblage derived from a newly contributing region or from freshly uncovered rocks within the old province.

The boundaries of the zones are generally not sharply defined, as by the abrupt occurrence in abundance of some new mineral. In the order of deposition in the geologic column, a new mineral ordinarily first appears in the sediments in traces and sporadically. Gradually it becomes more common and occurs continuously, and finally it may disappear in the same gradual manner as it appeared. This vertical sequence is more likely to occur where sedimentation has not been interrupted by a long erosion interval, and the vertical column of sediments reflects the gradual uncovering and erosion of new rock types within the distributive province or the gradual influx, as a result of currents, of sediments from another drainage area which also empties into the depositional basin. (For a more detailed discussion of the principles of stratigraphic correlation by mineral criteria see Milner.[4]) As a consequence of these features of mineral occurrence in the subsurface Cenozoic sediments of southern Louisiana, the position of a mineral-zone boundary is ordinarily not definitely marked and its determination is subject to the judgment of the investigator.

Where sedimentation has been interrupted by a long period of erosion or non-deposition, during which new rock types may have been uncovered in the hinterland and new drainages developed, it is probable that the sediments deposited after the period of non-deposition will be mineralogically different from those deposited prior to this period, and the surface of unconformity will be a well defined boundary between mineral zones.

Mineral-zone boundaries need not of necessity coincide with formation boundaries based on paleontology or lithology but may occur within formations and may transect formation boundaries and faunal horizons. A mineral-zone boundary may be much like a facies boundary between near-shore and deeper-water deposits accumulated under conditions of continuous sedimentation in a transgressing or regressing sea. This facies boundary will transect formations and faunal horizons.

[4] *Ibid.*

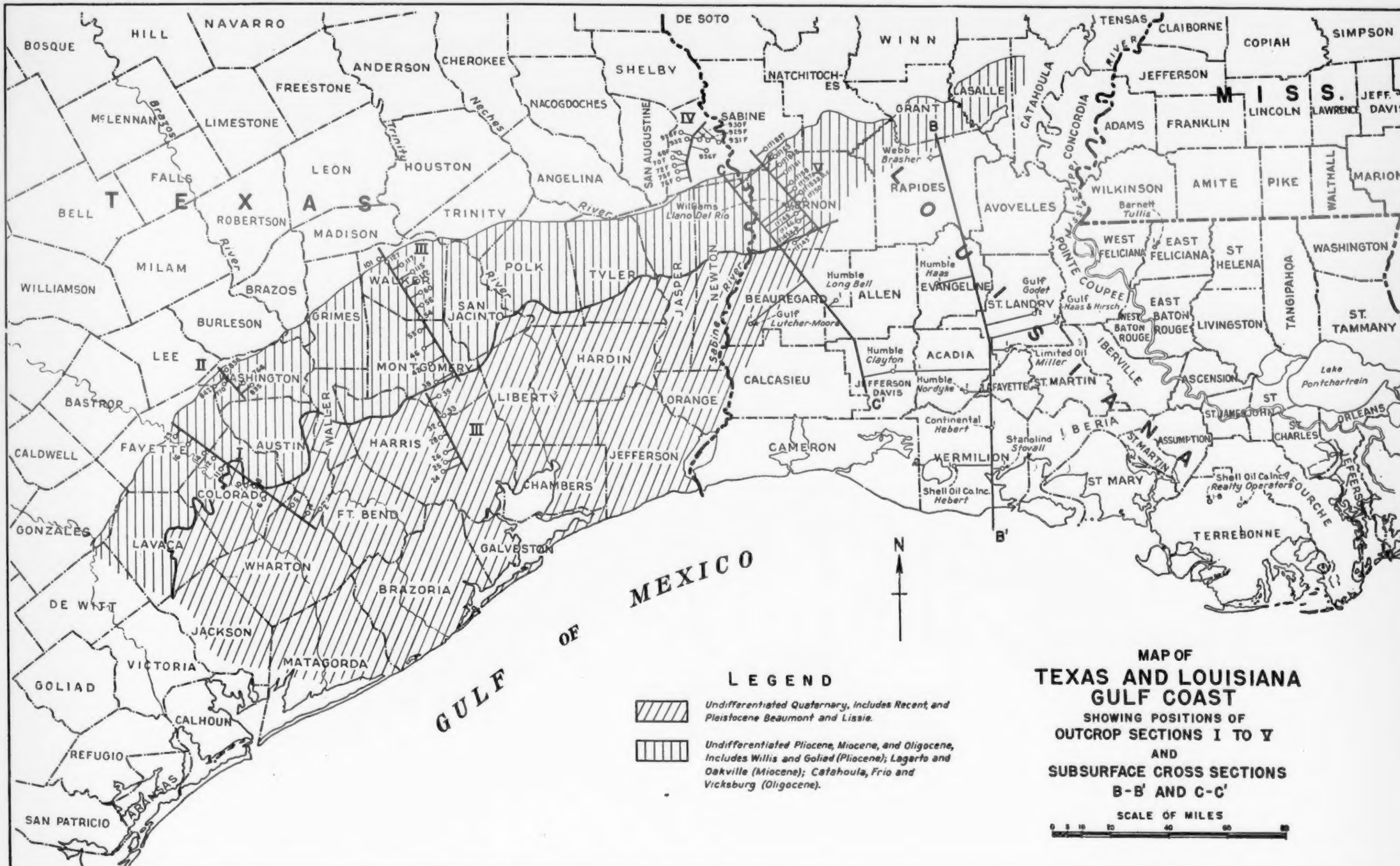

MAP OF
TEXAS AND LOUISIANA
GULF COAST
SHOWING POSITIONS OF
OUTCROP SECTIONS I TO V
AND
SUBSURFACE CROSS SECTIONS
B-B' AND C-C'
SCALE OF MILES
LEGEND
Undifferentiated Quaternary, includes Recent and Pleistocene Beaumont and Lissie.
Undifferentiated Pliocene, Miocene, and Oligocene, includes Willis and Goliad (Pliocene); Lagarto and Oakville (Miocene); Catahoula, Frio and Vicksburg (Oligocene).
GULF OF MEXICO
TEXAS
LOUISIANA
MISS.
N

FIG. 1

Fig. 1

HEAVY-MINERAL ZONES FOR STRATIGRAPHIC CORRELATION

In order to determine the reliability of heavy-mineral zones for stratigraphic correlation it is necessary that correlations of strata by heavy-mineral zones be compared with some reliable stratigraphic datum. Up to the present, in southern Louisiana the most reliable means for correlation of sediments between localities separated by distances of more than a few miles has been afforded by paleontologic criteria, particularly Foraminifera. Although many species of Foraminifera are known to possess a vertical range in the geologic column which varies from one locality to another, nevertheless, it has been found by careful study of the faunal variations along the dip and strike of the strata and by judicious choice of Foraminifera for marker criteria, that stratigraphic correlations of reasonable reliability can be made.

Sections (Figs. 2, 3) were constructed showing correlations of strata in southern Louisiana by means of heavy-mineral zones as compared with paleontologic horizons. In making the mineral-zone correlations on the cross sections, particularly those showing interfingering and stratigraphic ascent or descent of mineral zones in the geologic column, the writer was measurably guided by paleontologic control. Without paleontologic control, more of the mineral-zone boundaries would have been drawn as straight lines showing little or no interfingering. (See base of Epidote zone, Fig. 3.)

MINERAL ASSEMBLAGES CHARACTERIZING SUBSURFACE HEAVY-MINERAL ZONES

Four major heavy-mineral zones of widespread occurrence have been recognized in the subsurface Cenozoic sediments of southern Louisiana. In ascending order these have been termed the Staurolite, Kyanite, Epidote, and Hornblende zones. The Hornblende zone is erratic in its distribution, both vertically and laterally, and perhaps should be classed merely as a variation of the Epidote zone. In a few wells that have penetrated deeply into strata of Eocene age, another mineral zone has been recognized, the Lower Epidote zone.

The mineral zones down to the Lower Epidote zone show impoverishment in variety of mineral species successively with depth, and the boundaries between these zones represent the basal ranges of the diagnostic, zonal minerals. As a consequence of this mineral distribution, drill cuttings which are commonly contaminated by cavings from higher in the hole are impracticable for zone determinations and only cores were used in this study.

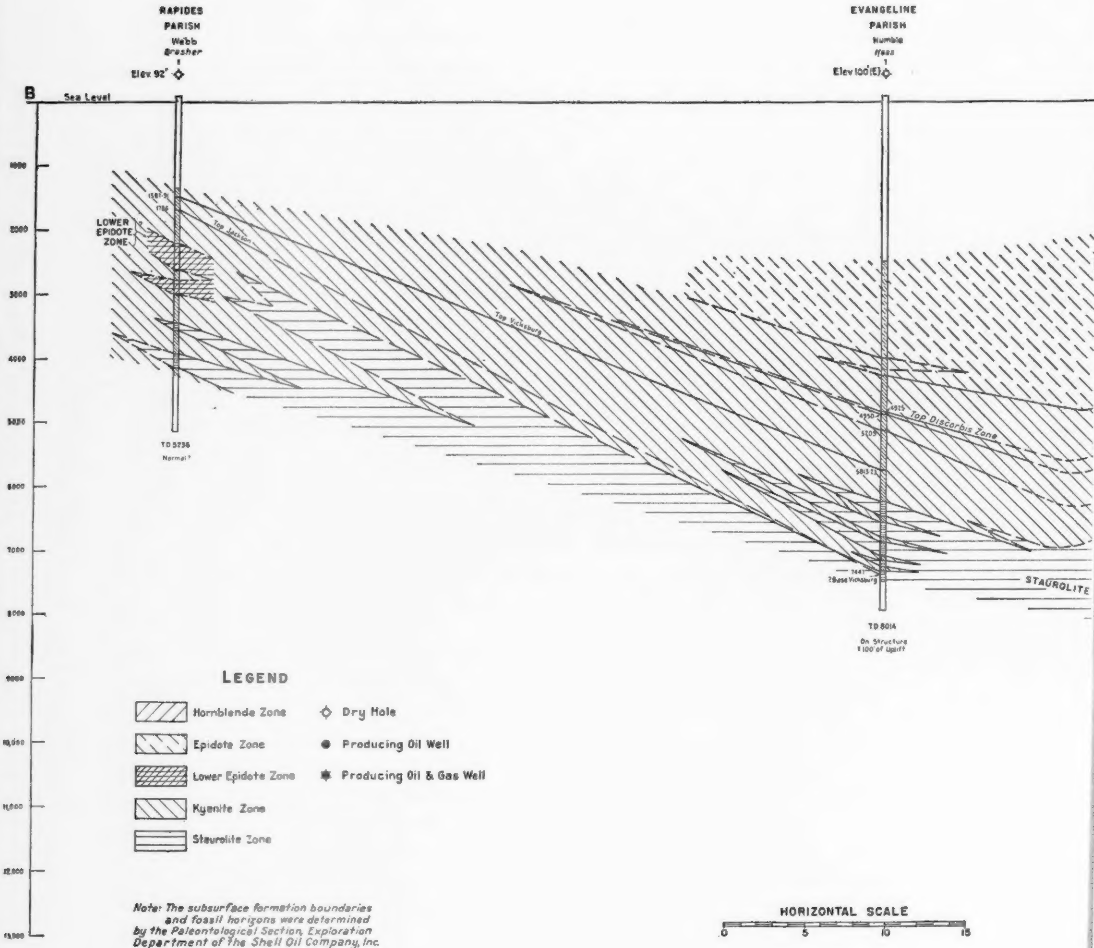
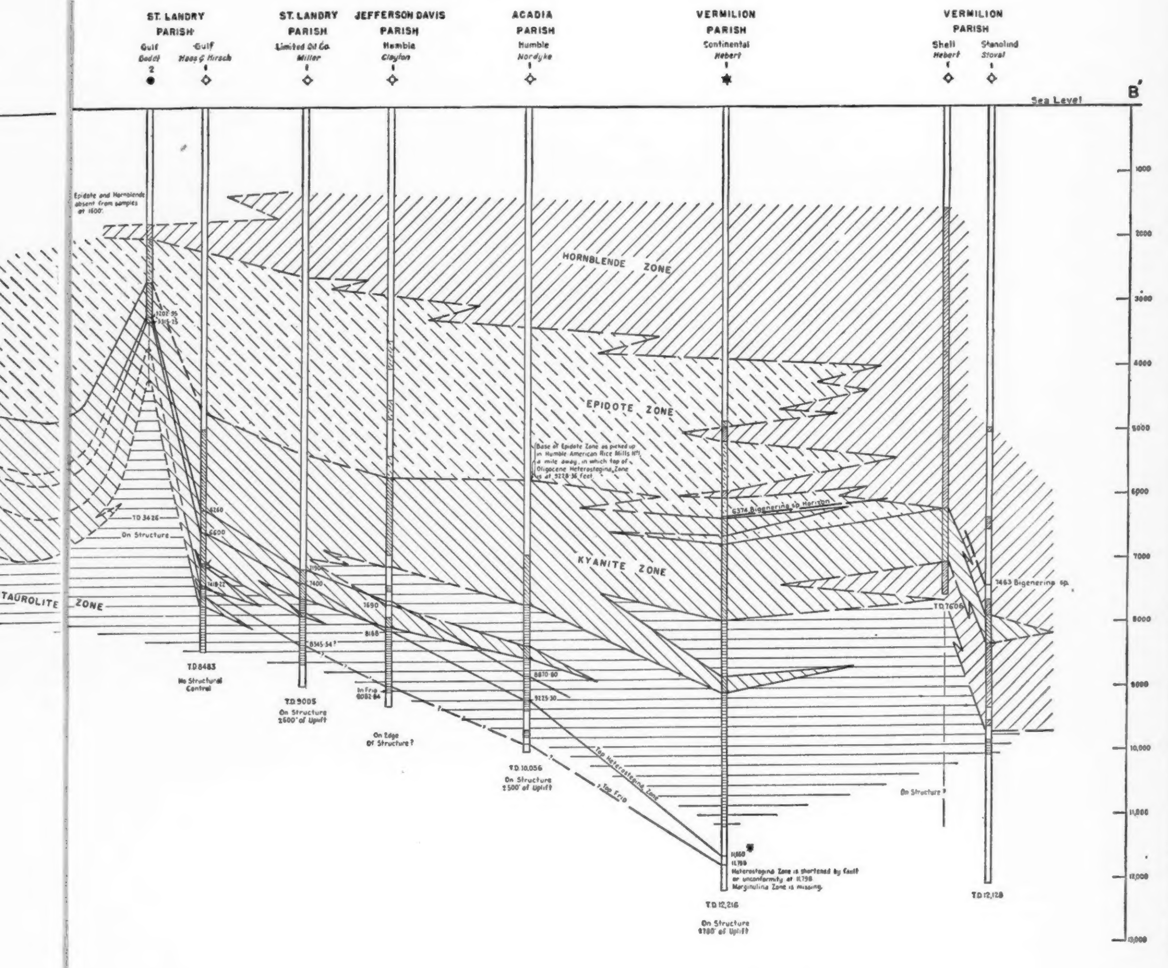


FIG. 2.—Cross section along line BB', showing heavy-mineral zones from Vermilion Parish to Rapides Parish, Louisiana. Vertical scale in feet. Horizontal scale in miles.



CROSS-SECTION ALONG LINE B-B'
SHOWING
HEAVY MINERAL ZONES
FROM VERMILION PARISH TO
RAPIDES PARISH, LOUISIANA

FIG. 2 (concluded).—SUBSEQUENT NOTE. *Recent review of paleontologic data for Continental's Hebert No. 1, Vermilion Parish, indicates probable top of *Discorbis* zone at depth of 11,650 feet. Tops of *Heterostegina* zone and Frio indeterminate.

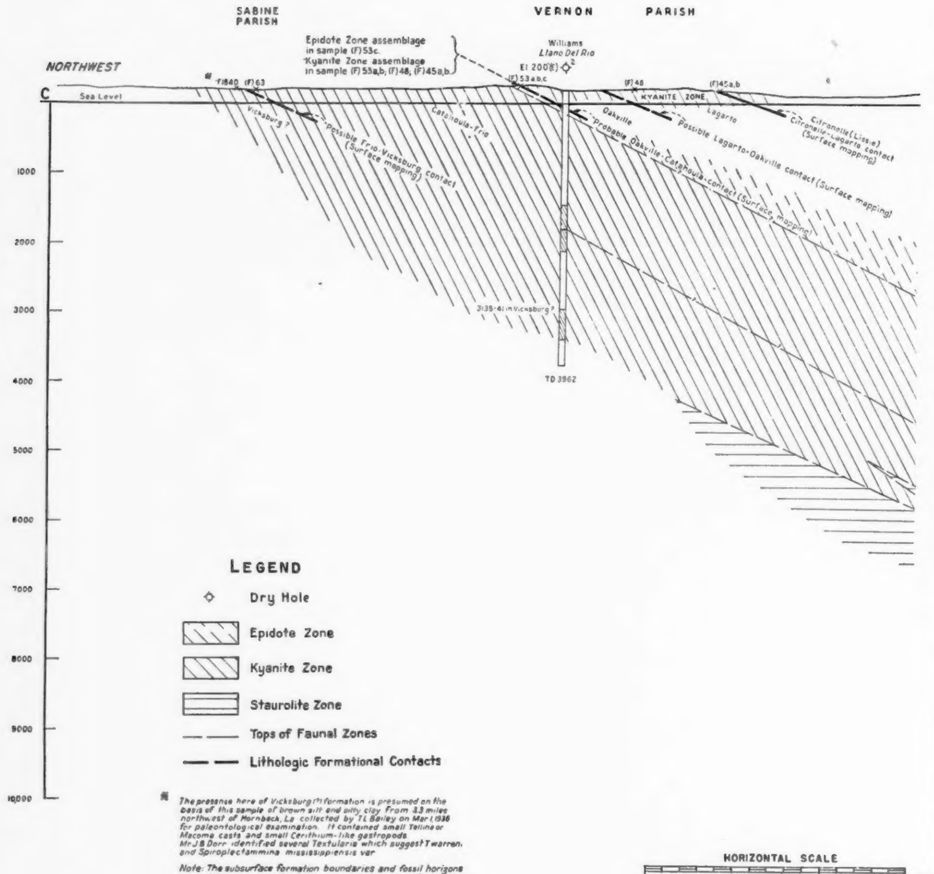
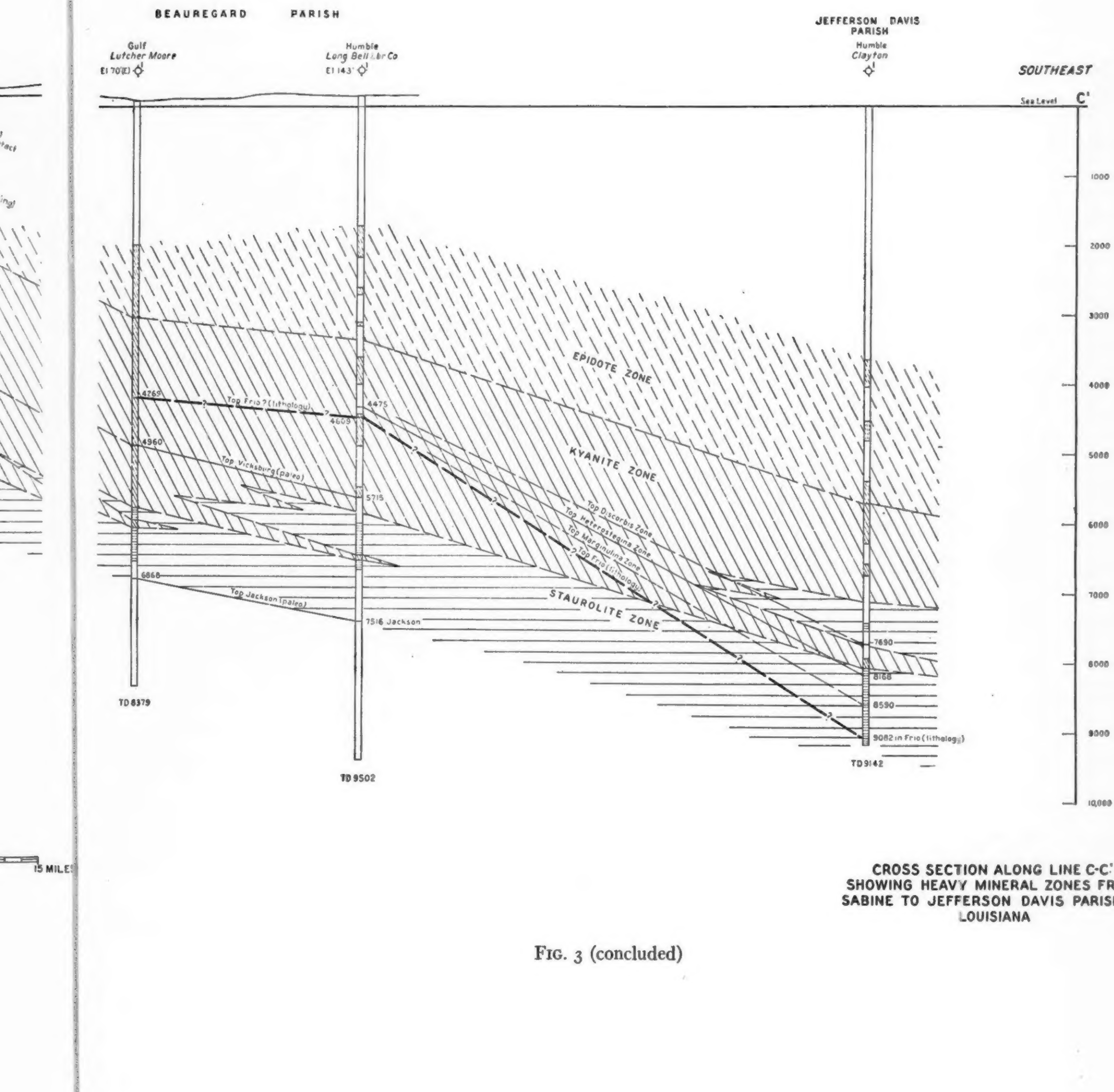
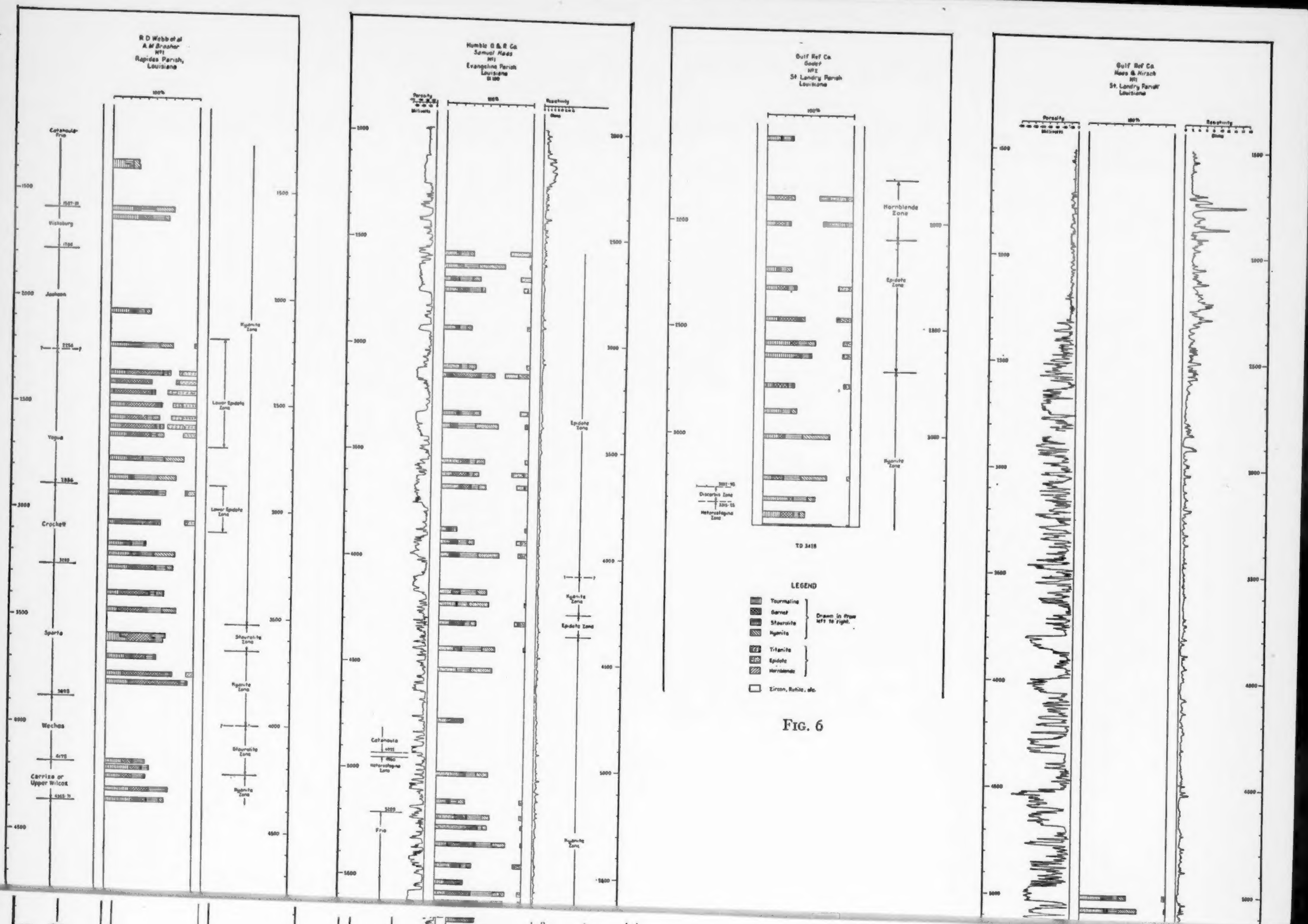


FIG. 3.—Cross section along line CC', showing heavy-mineral zones from Sabine to Jefferson Davis Parish, Louisiana. Vertical scale in feet.



CROSS SECTION ALONG LINE C-C'
SHOWING HEAVY MINERAL ZONES FROM
SABINE TO JEFFERSON DAVIS PARISH,
LOUISIANA

FIG. 3 (concluded)



R D Webb et al
A M Brasher
Nº1
Rapides Parish,
Louisiana
Humble O & R Co
Samuel Haas
Nº1
Evangeline Parish
Louisiana
Gulf Ref Co
Godet
Nº2
St Landry Parish
Louisiana
Gulf Ref Co
Haas & Hirsch
Nº1
St. Landry Parish
Louisiana
Porosity
Millivolts
100%
Resistivity
Ohms
Catahoula-Frio
Vicksburg
Jackson
Yegua
Crockett
Sparta
Weches
Carrizo or Upper Wilcox
Kyanite Zone
Lower Epidote Zone
Staurolite Zone
Epidote Zone
Hornblende Zone
Discorbis Zone
Heterostegina Zone
Catahoula
Frio
TD 3418
LEGEND
Tourmaline
Garnet
Staurolite
Kyanite
Drawn in from left to right.
Titanite
Epidote
Hornblende
Zircon, Rutile, etc.

FIG. 6

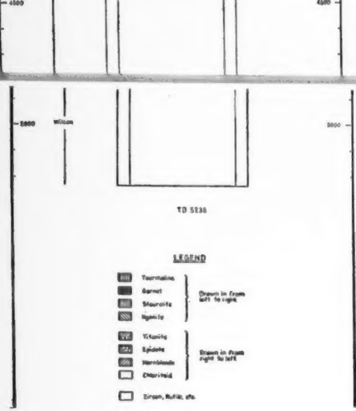


FIG. 4

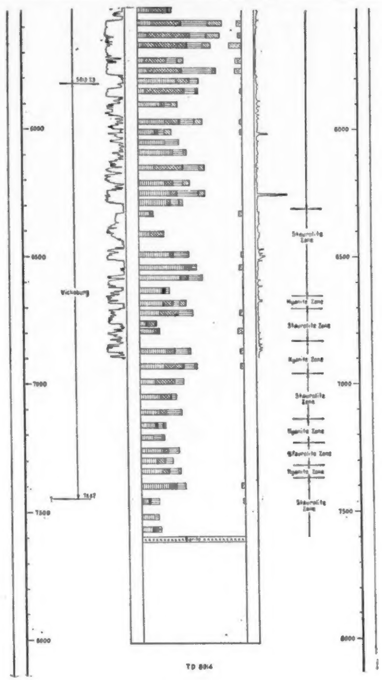


FIG. 5

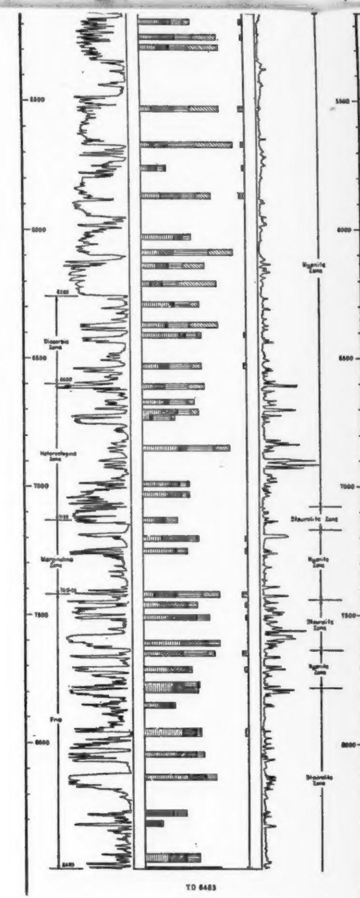
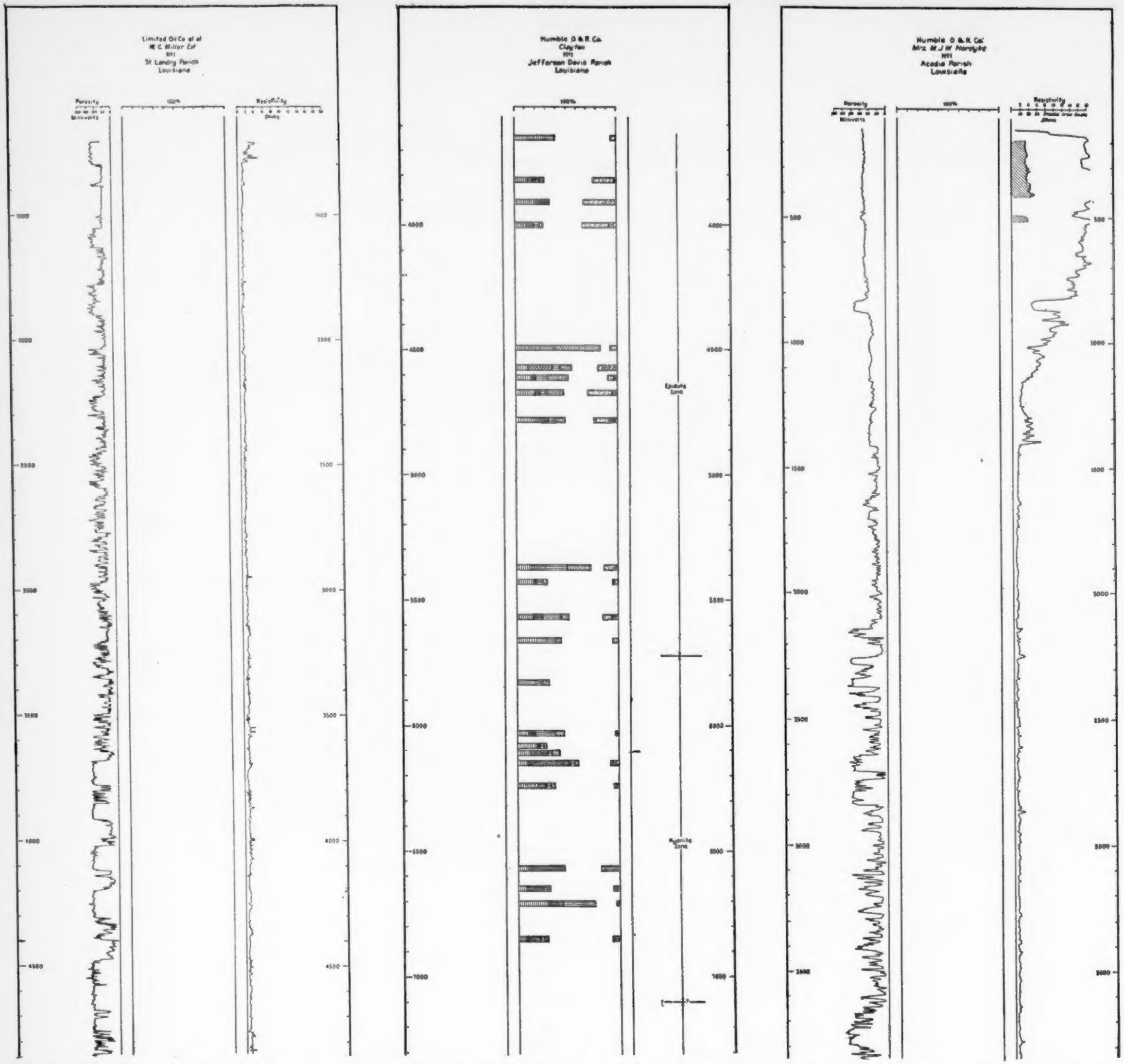


FIG. 7



Limited Oil Co et al
W C Miller Est
Nº1
St Landry Parish
Louisiana
Porosity
Millivolts
100%
Resistivity
Ohms
Humble O & R Co.
Clayton
Nº1
Jefferson Davis Parish
Louisiana
100%
Humble O & R Co.
Mrs. M J W Nordyke
Nº1
Acadia Parish
Louisiana
Porosity
Millivolts
100%
Resistivity
Ohms

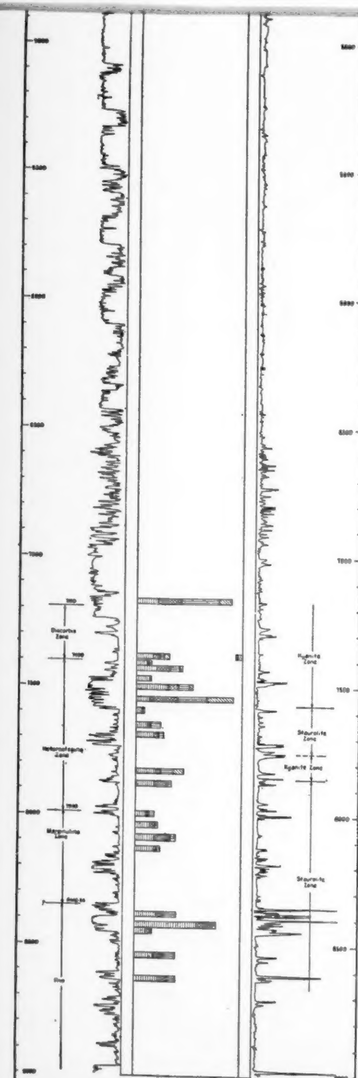


FIG. 8

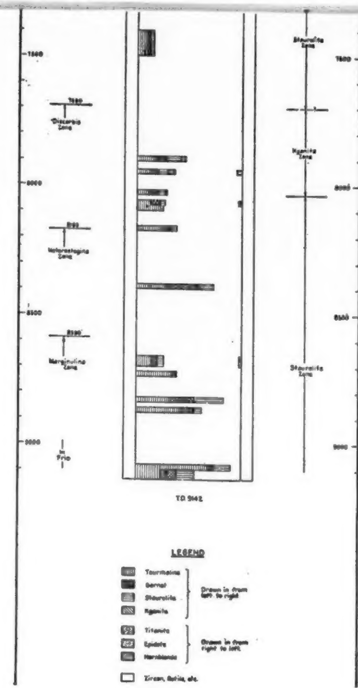
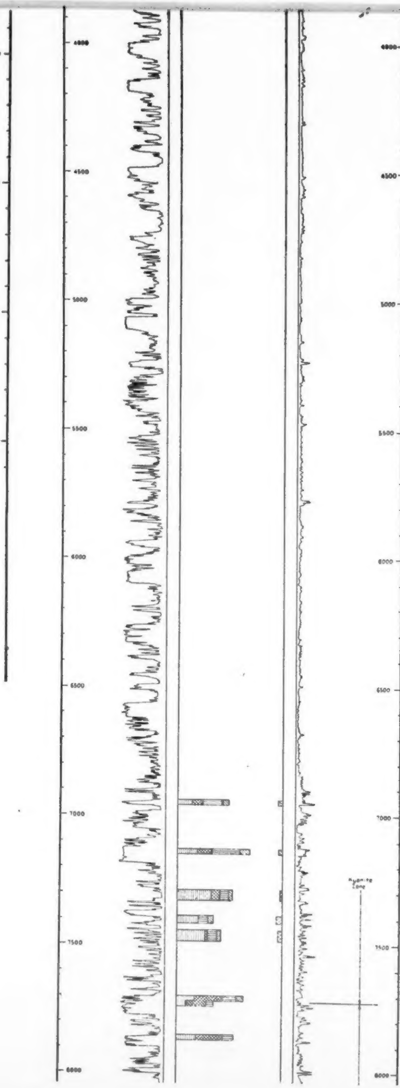


FIG. 9



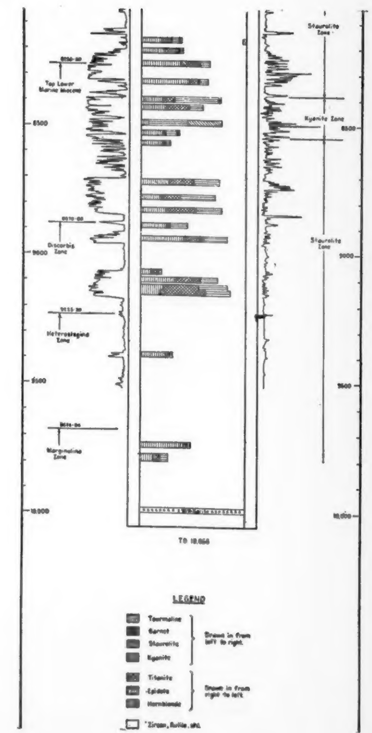
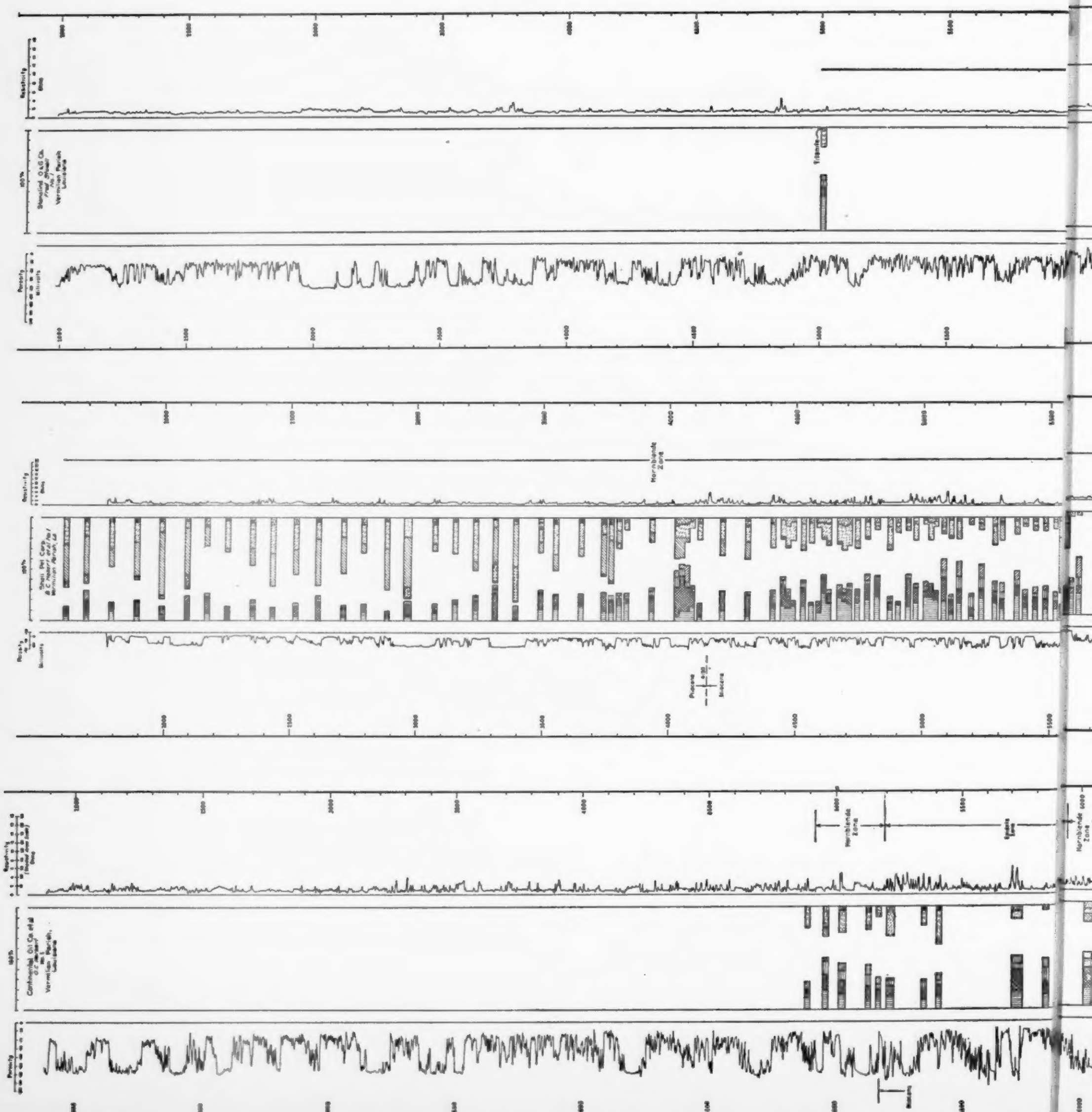


FIG. 10



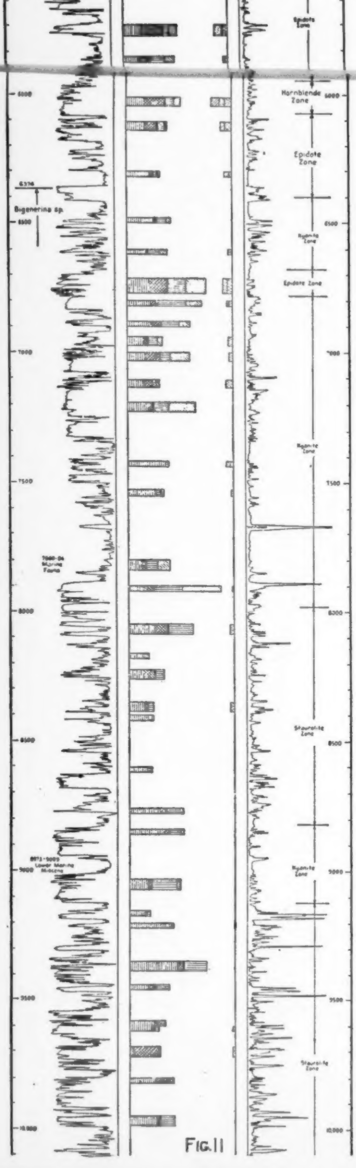


FIG. 11

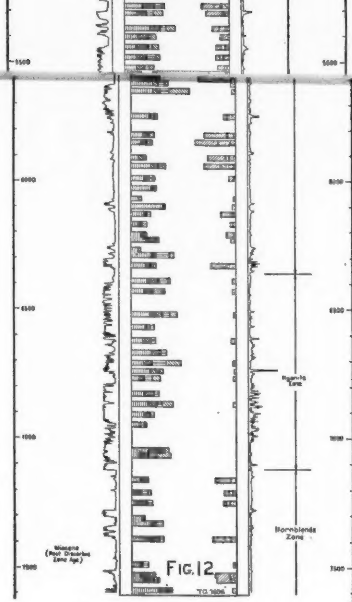


FIG. 12

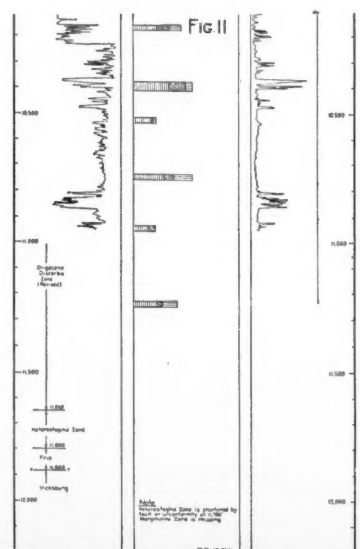


FIG. 11

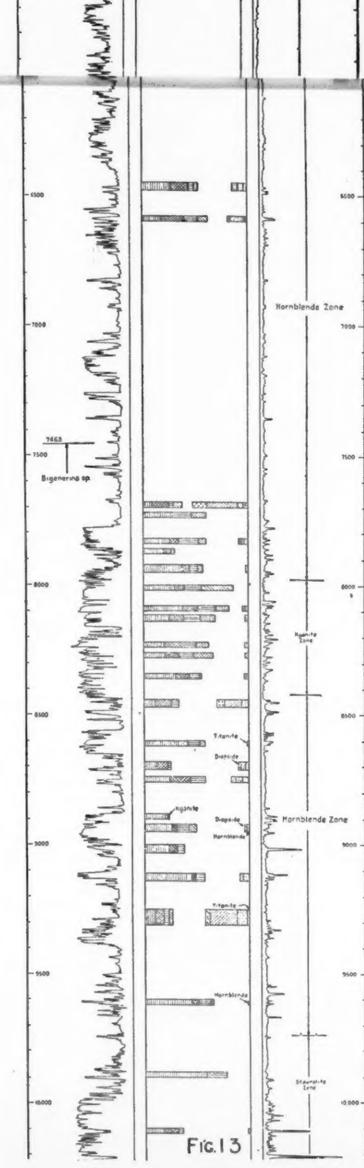


FIG. 13

SUBSEQUENT NOTE (Fig. 11, this page).—Recent review of paleontologic data for Continental's Hebert No. 1, Vermilion Parish, indicates probable top of *Discorbis* zone at depth of 11,650 feet. Tops of *Heterostegina* zone and Frio indeterminate.

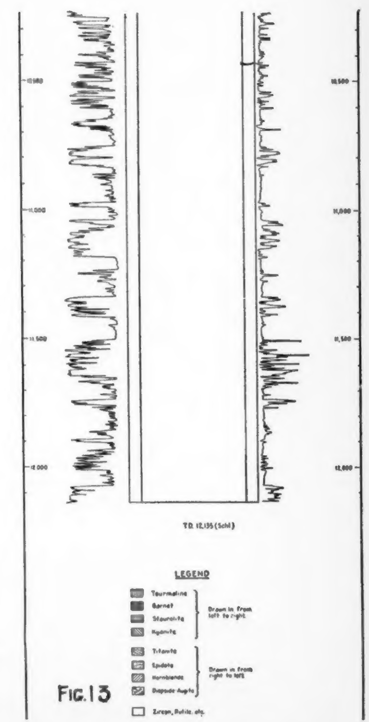
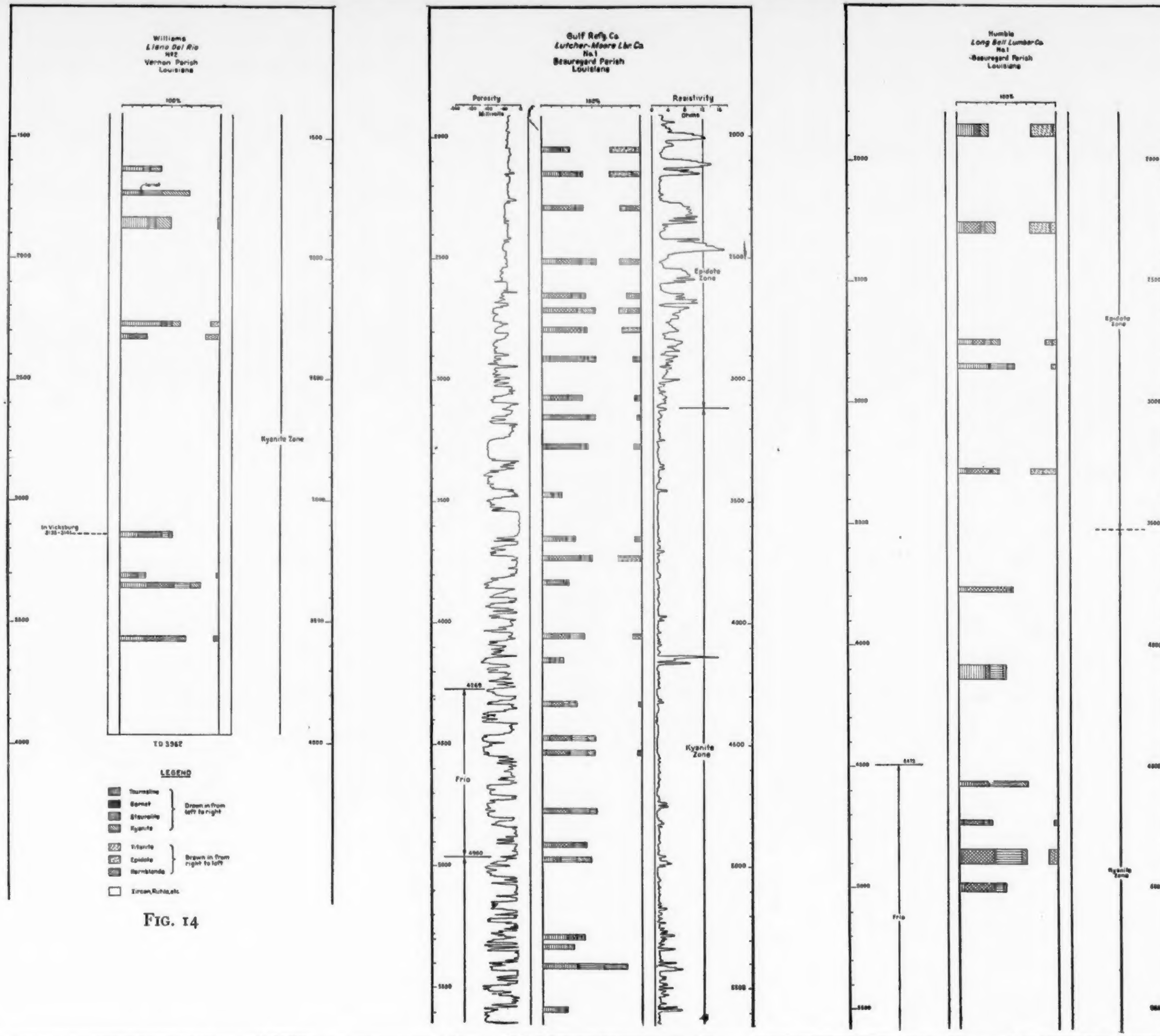
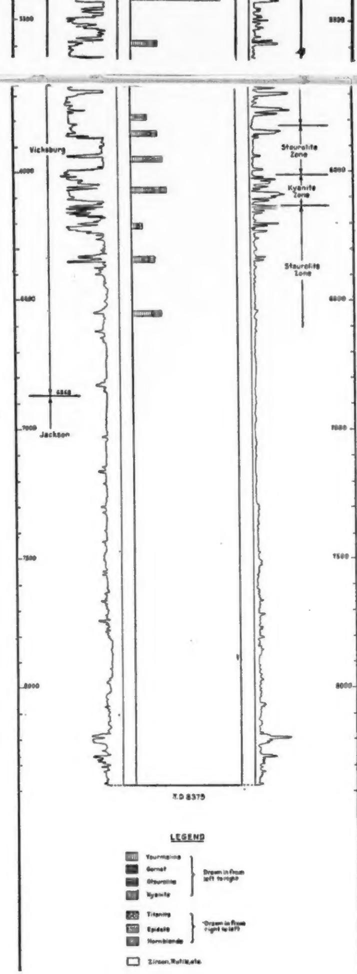


FIG. 13



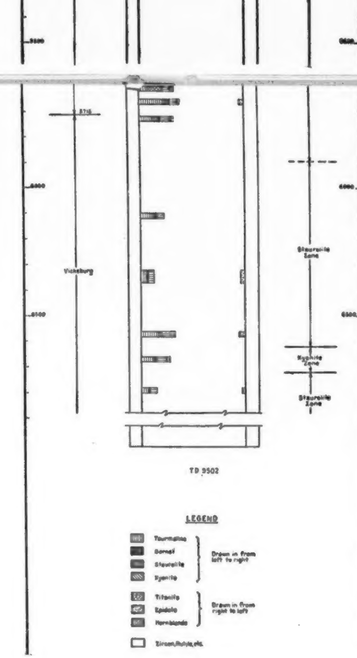
Williams
Llano Del Rio
No 2
Vernon Parish
Louisiana
Kyanite Zone
In Vicksburg
TD 3962
LEGEND
Tourmaline
Garnet
Staurolite
Kyanite
Drawn in from left to right
Titanite
Epidote
Hornblende
Drawn in from right to left
Zircon, Rutile, etc.
Gulf Ref'g Co.
Lutcher-Moore Lbr Co.
No. 1
Beauregard Parish
Louisiana
Porosity
Millivolts
Resistivity
Ohms
Epidote Zone
Kyanite Zone
Frio
4268
4960
Humble
Long Bell Lumber Co.
No. 1
Beauregard Parish
Louisiana
Epidote Zone
Kyanite Zone
Frio

FIG. 14



Vicksburg
6848
Jackson
Staurolite Zone
Kyanite Zone
Staurolite Zone
T.D 8375
LEGEND
Tourmaline
Garnet
Staurolite
Kyanite
Drawn in from left to right
Titanite
Epidote
Hornblende
Drawn in from right to left
Zircon, Rutile, etc.

Fig. 15



5716
Vicksburg
Staurolite Zone
Kyanite Zone
Staurolite Zone
T D 9502
LEGEND
Tourmaline
Garnet
Staurolite
Kyanite
Drawn in from left to right
Titanite
Epidote
Hornblende
Drawn in from right to left
Zircon, Rutile, etc.

Fig. 16

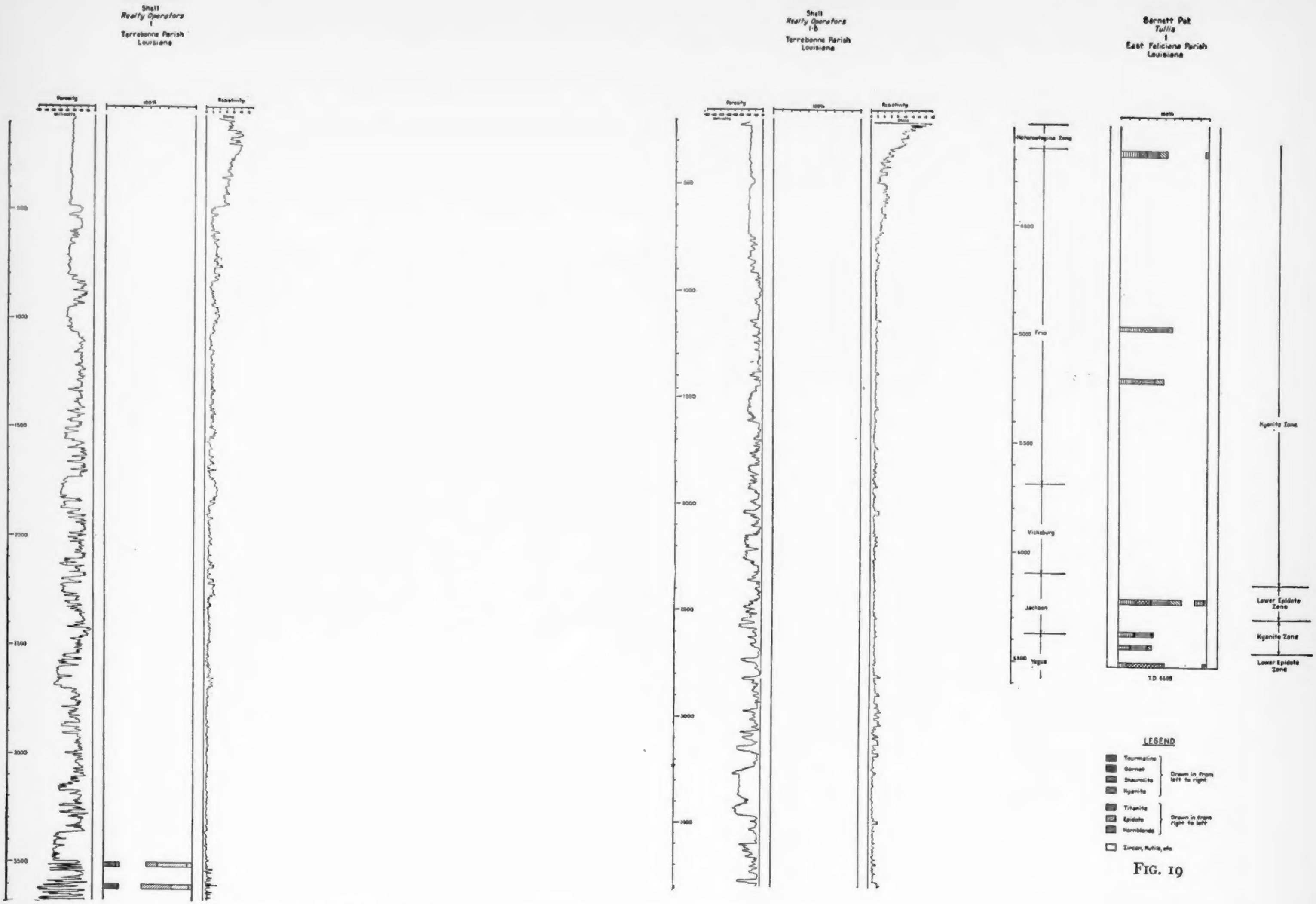

Shell
Realty Operators
1
Terrebonne Parish
Louisiana
Shell
Realty Operators
1-B
Terrebonne Parish
Louisiana
Bernett Pet
Tullis
1
East Feliciana Parish
Louisiana
Porosity
Resistivity
100%
Heterostegina Zone
Frio
Vicksburg
Jackson
Yegua
T.D. 6508
Kyanite Zone
Lower Epidote Zone
Kyanite Zone
Lower Epidote Zone
LEGEND
Tourmaline
Garnet
Staurolite
Kyanite
Drawn in from left to right
Titanite
Epidote
Hornblende
Drawn in from right to left
Zircon, Rutile, etc.

FIG. 19

FIG. 19

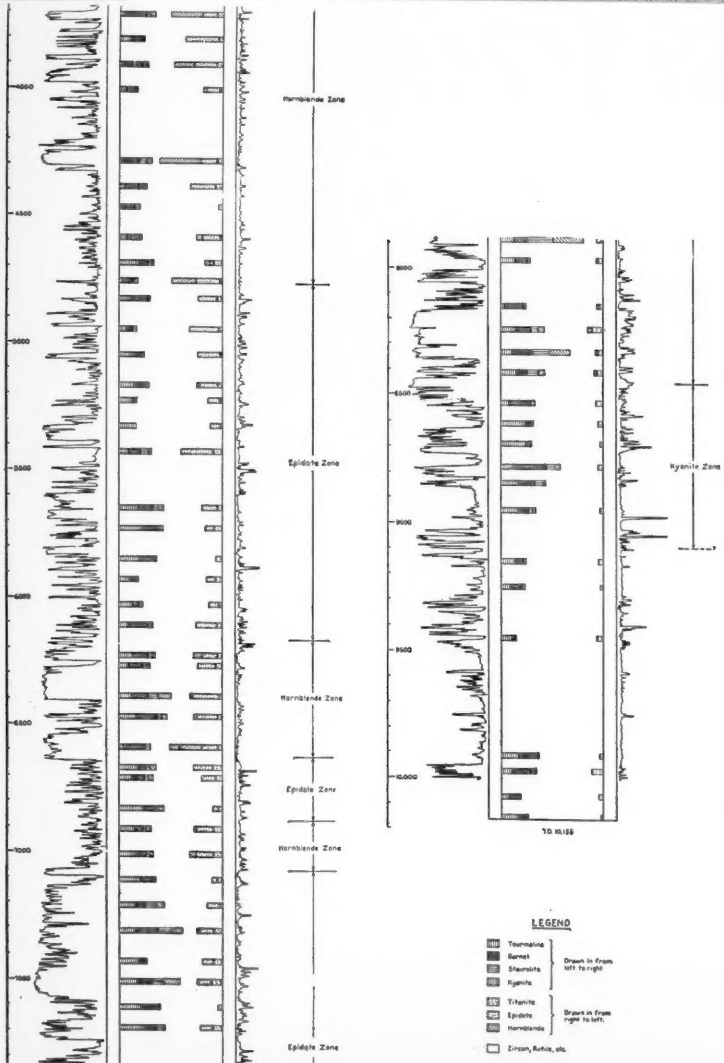


FIG. 17

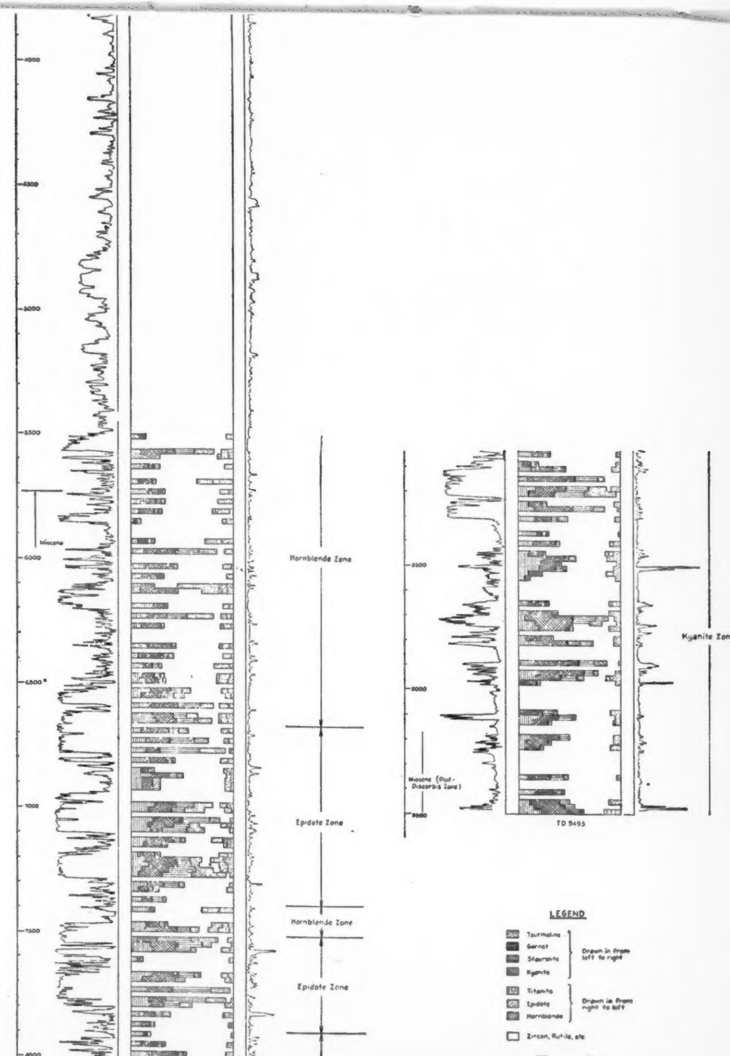


FIG. 18

LOWER EPIDOTE ZONE ASSEMBLAGE

The Lower Epidote zone is so termed to distinguish it from the Epidote zone higher in the section. Both zones carry epidote, but the two are separated from one another by a thick interval of non-epidote-bearing sediments. The Lower Epidote zone is not well known because of insufficient data. It is best developed in the Eocene strata penetrated by Webb's Brasher No. 1 in Rapides Parish, Louisiana (Fig. 4), where it is interjacent in the Kyanite zone and is characterized by a mineral assemblage which includes epidote, titanite, garnet, tourmaline, zircon, kyanite, and staurolite. The minerals characterizing the Lower Epidote zone differ from those of the Kyanite zone assemblage by the presence of both epidote and titanite. Titanite is more abundant than epidote through most of this zone and appears to be equally diagnostic of it. Perhaps Titanite zone would have been a more appropriate name for it.

STAUROLITE ZONE ASSEMBLAGE

The mineral content of the Staurolite zone is known best from wells south of Evangeline Parish (Figs. 9 and 11). Staurolite is its characteristic mineral. Zircon, tourmaline, and pink garnet are abundant, and rutile is generally present in small amounts. This zone is distinguished from the one overlying it by the absence of kyanite. It is poorest of all the zones in variety of mineral species. The minerals found in the Staurolite zone occur with additional minerals through all of the other zones.

KYANITE ZONE ASSEMBLAGE

The Kyanite zone is known from many wells (Figs. 6 and 7). Its heavy minerals in the subsurface sediments are like those of the Staurolite zone except for the addition of kyanite. In the outcropping formations farther toward the interior the Kyanite zone is generally free from garnet.

EPIDOTE ZONE ASSEMBLAGE

The mineral assemblage of the Epidote zone is characterized by the presence of epidote which serves to distinguish this zone from all of the underlying ones previously described except the Lower Epidote zone. However, there is little likelihood of confusing the two Epidote zones, inasmuch as they are separated vertically by a considerable thickness of strata free from epidote. Associated with epidote in this zone are zircon, pink garnet, tourmaline, staurolite, and kyanite in abundance. Titanite and rutile are generally present in small amounts.

HORNBLENDE ZONE ASSEMBLAGE

The Hornblende zone is characterized specifically by the presence

TABLE I

GUIDE TO FORMATION NAMES

Age	*Texas*			*Louisiana*		*Mississippi*
Pleistocene	Houston		Beaumont		Beaumont	Port Hudson
	Houston		Lissie		Lissie	Natchez
Pliocene	Fleming Citronelle		Willis	Citronelle	Willis	Citronelle
	Fleming Citronelle		Goliad	Citronelle	Goliad ?	
Miocene	Fleming Citronelle		Lagarto		Fleming	Pascagoula
	Fleming Citronelle		Oakville			Hattiesburg clay
Oligocene	Gueydan		Catahoula		*Catahoula	Catahoula
	Gueydan	Subsurface	*Discorbis* zone	Subsurface	*Discorbis* zone	
	Gueydan	Subsurface	*Heterostegina* zone	Subsurface	*Heterostegina* zone	
	Gueydan	Subsurface	*Marginulina* zone	Subsurface	*Marginulina* zone	
	Gueydan		Frio Vicksburg		Frio Vicksburg	
Eocene			Jackson			
	Claiborne		Yegua Crockett Stone City Sparta Weches Queen City Reklaw Carrizo			
			Wilcox			
			Midway			

* Strata classified as Miocene on the heavy-mineral well logs include the Catahoula formation.

of hornblende (Fig. 12). In addition, epidote, garnet, tourmaline, staurolite, kyanite, and zircon are present in amounts ordinarily exceeding 5 per cent and titanite is generally present in smaller amounts. Diopside-augite occurs sporadically in moderate abundance. Small amounts of other heavy minerals occur in few samples.

OUTCROP SECTIONS AND THEIR MINERAL ASSEMBLAGES

Outcrop samples were collected by T. L. Bailey assisted by C. W. Fulcher or the writer from various localities in Texas and Louisiana along the belt of outcropping Cenozoic formations which roughly

parallels the Gulf Coast. Five sections,[5] each of which crosses Cenozoic formations at intervals along the outcrop belt from the drainage basin of the Colorado River in Texas, northeastward to west-central Louisiana, were developed from these collections.

SECTION I. FROM VICINITY OF EAST BERNARD, WHARTON COUNTY, TO LA GRANGE, FAYETTE COUNTY, TEXAS (FIG. 20)

This is the most westerly section studied. It crosses formations ranging from the Beaumont to the Catahoula. In these formations, the Kyanite, Epidote, and Hornblende zones are represented. The Kyanite zone occurs in the one sample representing the Willis? or Goliad? formation. It differs here from its subsurface counterpart by the absence of garnet. The epidote assemblage was found in the Catahoula formation and in parts of the Oakville, Lagarto, Lissie, and Beaumont formations interleaved with strata containing the hornblende assemblage. Hornblende in exceptional abundance was found in the lower part of the Lagarto formation.

SECTION II. FROM VICINITY OF BRENHAM, WASHINGTON COUNTY, TO VICINITY OF CARMINE, FAYETTE COUNTY, TEXAS (FIG. 21)

This is a short section in which the Lagarto, Oakville, and Catahoula formations are represented. All three formations are here characterized by the Epidote zone minerals.

SECTION III. FROM HOUSTON, HARRIS COUNTY, TO 11 MILES NORTHWEST OF HUNTSVILLE, WALKER COUNTY, TEXAS (FIG. 22)

This section is about 70 miles northeast of section II and crosses formations ranging in age from Beaumont to Jackson. Mineralogically, the formations in this section differ strikingly from the corresponding formations in sections I and II. Here the kyanite assemblage is far more prominent than the epidote assemblage, and, as in outcrop

[5] In order to illustrate conveniently the mineral content of successively exposed formations, the following procedure was used.

Sample localities were carefully marked on a small-scale map (1 inch equals 8 miles). A section line across the strike of the formations was drawn on the map, and the position of each locality was projected parallel with the general strike of the formations onto this line. The projected positions of the sample localities along this line were transferred to a strip log (Figs. 20–24) starting with the stratigraphically youngest formation at the top. Opposite the number of each sample locality was plotted its mineral record. On the log the vertical distance between sample records is proportionate to the horizontal distance between sample localities as measured along the section line on the map, and the horizontal distance between sample localities is roughly proportionate to the thickness of the intervening sediments. Differences in ground elevation of sample localities and variations in dip of the strata introduce a certain amount of error in the thickness of the stratigraphic interval between localities as recorded on the strip log, but the general sequence of the localities and their approximate position in the geologic column show up well.

section I (Fig. 20), the kyanite assemblage differs from its subsurface analogue by being, for the most part, devoid of garnet. Hornblende is absent from all of the formations. Only the kyanite and epidote assemblages occur, and they are interleaved.

Except for traces, epidote is absent from the Beaumont and Lissie formations. It is totally absent from the Willis formation. It occurs in the Lagarto and uppermost Oakville strata, associated with garnet and here and there small amounts of titanite. From the middle and lower part of the Oakville formation, epidote and garnet are absent. Epidote in association with garnet and titanite occurs through all but the basal portion of the Catahoula formation, and a trace of epidote was found in the Jackson strata.

Where epidote is absent the strata are characterized by the kyanite assemblage. This interleaving of epidote and kyanite associations is suggestive of interfingering between sediments derived from different provinces.

SECTION IV. FROM PINELAND TO SABINETOWN, SABINE COUNTY, TEXAS (FIG. 23)

This section crosses Eocene formations ranging in age from Jackson to Carrizo. The formations, with exception of the upper part of the Yegua, are characterized by the kyanite assemblage devoid of garnet except for a few traces. The upper part of the Yegua contains abundant garnet and titanite with traces of epidote. This assemblage may be the surface expression of the Lower Epidote zone found in the subsurface of Louisiana.

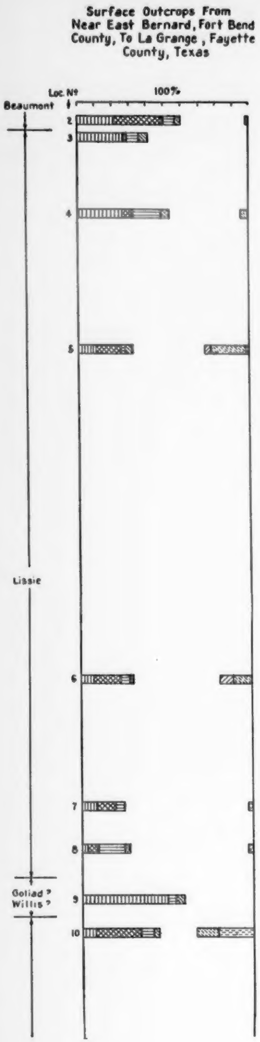
SECTION V. FROM VICINITY OF ROSEPINE, VERNON PARISH, TO SANDEL, SABINE PARISH, LOUISIANA (FIG. 24)

This section crosses formations ranging in age from Lissie? to Vicksburg. Most of the formations are characterized by the kyanite assemblage devoid of garnet. Epidote occurs abundantly only in the upper part of the Catahoula formation where it is associated with garnet and titanite. It is absent, except for sporadic traces, from all of the other formations. This is equally true for garnet and titanite.

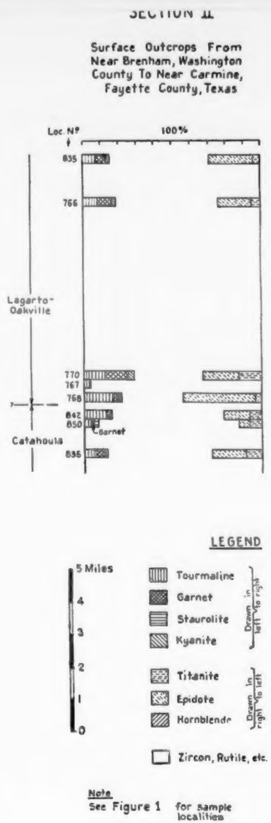
SUMMARY AND INTERPRETATION OF OUTCROP SECTIONS

Careful study of the mineral assemblages from the outcropping formations clearly shows interfingering and pinching-out laterally of various of the mineral zones along the outcrop belt.

Hornblende zone.—The hornblende assemblage was found only along outcrop section I which is in the drainage basin of the Colorado River of Texas and is farthest west of the sections studied. Here the

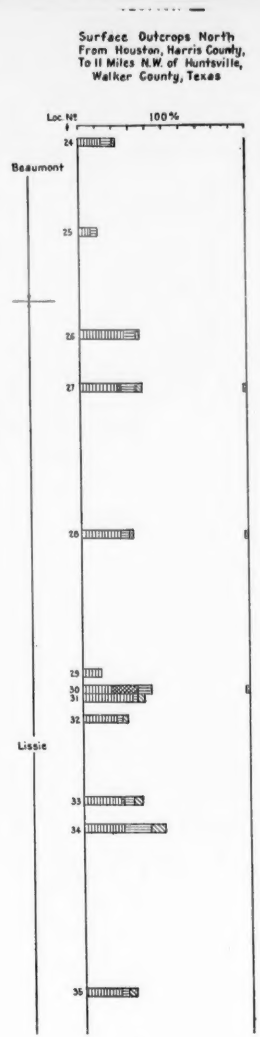


Surface Outcrops From Near East Bernard, Fort Bend County, To La Grange, Fayette County, Texas
Loc. Nº
100%
Beaumont
Lissie
Goliad ? Willis ?
2
3
4
5
6
7
8
9
10

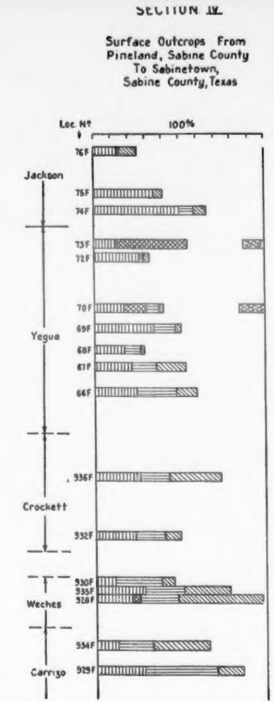


SECTION II
Surface Outcrops From Near Brenham, Washington County To Near Carmine, Fayette County, Texas
Loc. Nº
100%
Lagarto-Oakville
Catahoula
835
766
770
767
768
842
850
Garnet
836
LEGEND
5 Miles
4
3
2
1
0
Tourmaline
Garnet
Staurolite
Kyanite
Drawn in left to right
Titanite
Epidote
Hornblende
Drawn in right to left
Zircon, Rutile, etc.
Note
See Figure 1 for sample localities

FIG. 21

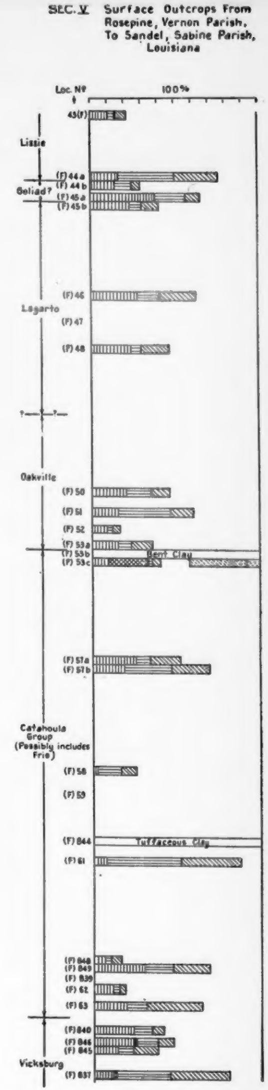


Surface Outcrops North From Houston, Harris County, To 11 Miles N.W. of Huntsville, Walker County, Texas
Loc. Nº
100%
Beaumont
Lissie
24
25
26
27
28
29
30
31
32
33
34
35



SECTION IV
Surface Outcrops From Pineland, Sabine County To Sabinetown, Sabine County, Texas
Loc. Nº
100%
Jackson
Yegua
Crockett
Weches
Carrizo
76F
75F
74F
73F
72F
70F
69F
68F
67F
66F
936F
932F
930F
935F
928F
934F
929F

FIG. 23



SEC. V
Surface Outcrops From Rosepine, Vernon Parish, To Sandel, Sabine Parish, Louisiana
Loc. Nº
100%
Lissie
Goliad?
Lagarto
Oakville
Catahoula Group (Possibly includes Frio)
Vicksburg
Bent Clay
Tuffaceous Clay
45(F)
(F) 44a
(F) 44b
(F) 45a
(F) 45b
(F) 46
(F) 47
(F) 48
(F) 50
(F) 51
(F) 52
(F) 53a
(F) 53b
(F) 53c
(F) 57a
(F) 57b
(F) 58
(F) 59
(F) 844
(F) 61
(F) 848
(F) 849
(F) 839
(F) 62
(F) 63
(F) 840
(F) 846
(F) 845
(F) 837

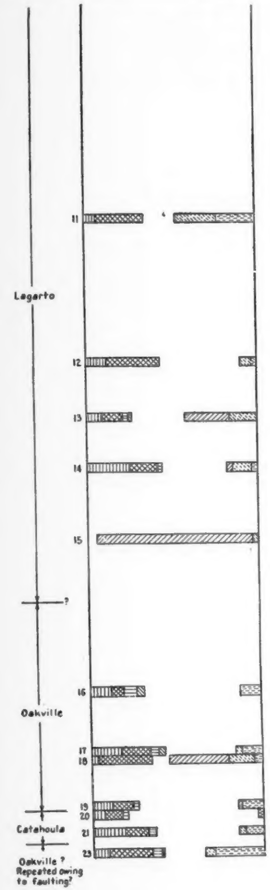
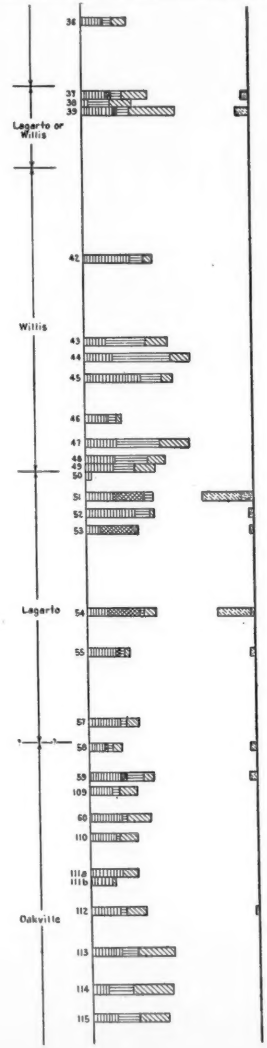

Lagarto
Oakville
Catahoula
Oakville ? Repeated owing to faulting?
11
12
13
14
15
16
17
18
19
20
21
23

FIG. 20


Lagarto or Willis
Willis
Lagarto
Oakville
36
37
38
39
42
43
44
45
46
47
48
49
50
51
52
53
54
55
57
58
59
109
60
110
111a
111b
112
113
114
115

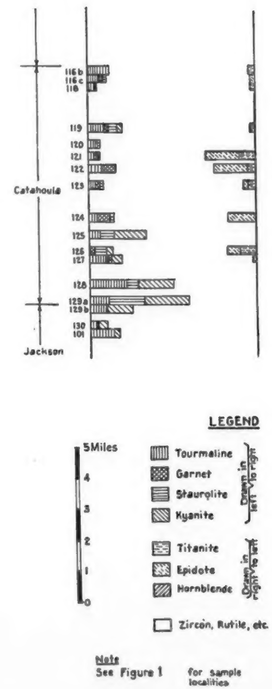

Catahoula
Jackson
116b
116c
118
119
120
121
122
123
124
125
126
127
128
129a
129b
130
101
LEGEND
5 Miles
4
3
2
1
0
Tourmaline
Garnet
Staurolite
Kyanite
Drawn in left to right
Titanite
Epidote
Hornblende
Drawn in right to left
Zircon, Rutile, etc.
Note
See Figure 1 for sample localities

FIG. 22

Hornblende zone was found in parts of the Lissie, Lagarto, and Oakville formations, interleaved with the Epidote zone. Hornblende is absent except for a few traces from these and other Cenozoic formations examined along the outcrop belt farther north and east. The most likely source of the hornblende in the formations along section I is the Llano-Burnet uplift of central Texas where metamorphic and igneous rocks are exposed. This region is drained today by the Colorado River and probably was drained by the ancestral Colorado as early as Oakville time. The Cenozoic formations along the outcrop belt farther to the north and east, in which only a few traces of hornblende occur, were probably derived from old sedimentary rocks deficient in hornblende.

Epidote zone and its eastward gradation into Kyanite zone.—The Epidote zone is well represented in the outcrops studied. Along section I in the Colorado River basin, the epidote assemblage was found in the Beaumont, Lissie, Lagarto, Oakville, and Catahoula formations. Passing northeastward to section II, it occurs in Lagarto, Oakville, and Catahoula rocks. Continuing eastward to section III, a definite change in mineral assemblage of the outcropping formations is observable. The kyanite assemblage has become dominant and is interleaved with the Epidote zone. The epidote assemblage is absent from the Beaumont formation, present only in traces through the Lissie, occurs in the Lagarto, and is absent from most of the Oakville. It occurs through the Catahoula formation almost down to its contact with the underlying Jackson. The data suggest that a new depositional province distinguished by the presence of the kyanite assemblage has been entered. Continuing northeastward to section V in Sabine Parish, Louisiana, the epidote assemblage is observed to be confined to a thin zone in the Catahoula-Frio formation just below its probable contact with overlying Oakville. The Oakville, Lagarto, and Lissie formations above this are devoid of epidote and carry a kyanite assemblage. Below this the Catahoula-Frio and Vicksburg formations are free of epidote and carry the kyanite assemblage.

From the outcrop data it appears that the Epidote zone fingers out from the Colorado River drainage basin toward the northeast, and that the epidote and kyanite assemblages are each characteristic of a different distributive province.

CORRELATION OF SUBSURFACE MINERAL ZONES WITH FORMATIONS EXPOSED AT SURFACE AND INTERPRETATION

Core samples from many wells in southern Louisiana were examined and sections were constructed showing the mineral zones in the

subsurface. These zones, in ascending order, are Lower Epidote zone, Staurolite zone, Kyanite zone, Epidote zone, and Hornblende zone.

LOWER EPIDOTE ZONE

The Lower Epidote zone is not well known. It occurs in rocks of Eocene age and was encountered in the subsurface in only two wells: Webb's Brasher No. 1 in Rapides Parish (Fig. 4) and Barnett's Tullis No. 1 in East Feliciana Parish, Louisiana (Fig. 19), along the northern edge of the region studied. The dip of the formations is southward, and the more southerly located wells did not penetrate to sufficient depth to encounter this zone.

The Lower Epidote zone is best defined in the Brasher No. 1 well where it is marked by a mineral assemblage which is essentially that of the Kyanite zone with an admixture of titanite and epidote. In this well, the Lower Epidote zone ranges from middle Crockett up through the Yegua and into basal Jackson and is divided into two members which occur as intercalations in the Kyanite zone.

In Barnett's Tullis No. 1, which penetrated less than 200 feet into the Yegua, the Lower Epidote zone is poorly marked and occurs in Yegua and Jackson strata. Here also the Lower Epidote zone is divided into two parts by a member of the Kyanite zone.

At the surface the probable extension of the subsurface Lower Epidote zone is represented in Sabine County, Texas, along outcrop section IV (Fig. 23), the only section among those studied which crosses Eocene formations older than the Jackson. Here in the upper Yegua there occurs a mineral assemblage rich in titanite and garnet and containing traces of epidote. This assemblage occurs as an intercalation in the Kyanite zone from which it differs distinctly by the presence of abundant titanite and garnet. As already described, the Lower Epidote zone in the subsurface is characterized by titanite even more dominantly than by epidote. Consequently, it is inferred from mineral composition and stratigraphic position, that the titanite-rich mineral assemblage in the Yegua outcrop of Sabine County marks the Lower Epidote zone.

It is clear from the fact that the Lower Epidote zone is divided into members by sediments containing a Kyanite assemblage, that it is either interbedded or interfingered with the Kyanite zone. This relationship suggests either that epidote and kyanite were each contributed to the basin of deposition from different distributive provinces or that the epidote was contributed by rocks newly exposed over a small area within the larger province furnishing the kyanite assemblage. The first hypothesis is somewhat more strongly supported by the additional fact that some strata within the Lower Epidote zone are free

from kyanite and therefore may have been derived from a province from which kyanite was absent.

STAUROLITE ZONE

The Staurolite zone is known exclusively from subsurface well data. In the subsurface sediments of the coastal parishes the staurolite assemblage occurs in sediments younger than *Discorbis* zone age. Passing from the coast inland and up the dip of the formations, the strongly interfingered boundary between the Staurolite and overlying Kyanite zones crosses the *Discorbis* zone into older formations, and in Rapides and West Feliciana parishes the top of the Staurolite zone is below the top of the Eocene Jackson formation (Fig. 2).

At the outcrop localities from which samples were collected in Texas and Louisiana, the kyanite assemblage occurs in strata of the same age as those which carry the staurolite assemblage in the subsurface of the coastal parishes of Louisiana. The presence of two mineral assemblages grading laterally one into the other in strata of equivalent age may be explained by the hypothesis that each was derived from a separate distributive province both of which drained into the same basin of deposition. One possible source of the Tertiary staurolite assemblage is the Cretaceous Woodbine formation of northeast Texas, parts of which contain abundant staurolite but little or no kyanite.

A second hypothesis is that currents exercised a panning or separating effect between kyanite and staurolite, dropping the former close to shore and carrying the latter farther out. This hypothesis is rather difficult to accept for it is contrary to what would be expected normally from the relative densities of the two minerals. The average density of kyanite is less than that of staurolite and it is to be expected that staurolite, the heavier of the two minerals, would be deposited closer to shore. The grain size of the two minerals in the sediments is about the same. In shape the kyanite is bladed, the staurolite equidimensional.

KYANITE ZONE

The main body of the Kyanite zone overlies the Staurolite zone, and its basal part is strongly interfingered with the upper part of the Staurolite zone. In cross section along the dip of the formations the Kyanite zone is shaped, roughly, like a wedge with the thin edge pointing coastward. This wedge thickens up the dip toward the north where it embraces a larger part of the Tertiary section by reason of its base having transgressed into older formations in passing from the coast inland (Figs. 2, 3). In the coastal parishes the thin edge of the Kyanite zone wedge occurs in sediments younger than *Discorbis* zone age. At

the surface in Vernon and Sabine parishes, Louisiana, the part of the Kyanite zone stratigraphically below the Epidote zone embraces formations ranging from near the top of the Catahoula-Frio, down well into the Eocene.

Along the outcrop belt the kyanite assemblage is prominent in many Tertiary formations exposed northeast from Montgomery County, Texas, to west-central Louisiana. However, the assemblage at the surface differs mineralogically from its counterpart in the subsurface in one respect. Garnet is rare or absent from the kyanite assemblage of the rocks exposed at the surface but is present in moderate abundance in nearly all samples from the Kyanite zone of the subsurface.

From the combined surface and subsurface data it appears that the garnet-free kyanite assemblage, composed essentially of kyanite, staurolite, tourmaline, and zircon, was borne into southern Louisiana from the north and northeast. In the more southerly, subsurface sediments which were probably deposited below strand line, the kyanite assemblage is enriched by abundant garnet that was carried, probably from the east or west by longshore currents. The transgression by the base of the Kyanite zone from Eocene formations in the interior to Miocene formations in the coastal parishes suggests that sediments bearing the kyanite assemblage were laid down in southern Louisiana as near-shore or deltaic deposits which, with the passage of time, were intermittently but progressively extended basinward or southward, while, contemporaneously in the deeper part of the basin, sediments derived from another distributive province and marked by the staurolite assemblage were being deposited.

EPIDOTE ZONE

The Epidote zone has been penetrated by many wells in southern Louisiana. In the subsurface sediments it lies directly above the Kyanite zone from which it differs mineralogically by the addition of epidote. The base of the Epidote zone is not sharply defined. In passing upward from the Kyanite zone to the Epidote zone there are several hundred feet of sediments in which only sporadic traces of epidote occur; gradually epidote becomes more abundant and continuous in occurrence. In consequence of these features, the determination of the base of the Epidote zone is likely to vary within a few hundred feet, according to the judgment of the investigator.

The base of the Epidote zone has been traced in the subsurface sediments up the dip from the coastal parishes as far north as Beauregard, Evangeline, and East Baton Rouge parishes. It lies above the *Discorbis* zone as far up the dip as the latter extends. The base of the Epidote

zone is not parallel with the top of the *Discorbis* zone but diverges from it down the dip as the sedimentary interval between the two thickens. No fossil horizons reliable for correlation of strata above the *Discorbis* zone and near the stratigraphic position of the base of the Epidote zone have yet been established except in the parishes bordering the coast. Consequently, it is not possible to determine to what degree the base of the Epidote zone transgresses paleontologic horizons in the region north of the coastal parishes. In Vermilion Parish a faunal horizon above the *Discorbis* zone, which is shown on Figure 2 as the *Bigenerina* sp. horizon, is considered[6] to be reliable for stratigraphic correlation. The position of the base of the epidote-bearing strata relative to the *Bigenerina* sp. horizon in two wells of Vermilion Parish suggests that the base of the Epidote zone transgresses toward the coast into older strata. In the Continental's Hebert No. 1, Vermilion Parish, the base of the lowest body of epidote-bearing sediments is about 400 feet below the *Bigenerina* sp. horizon. About 16 miles southward in the Stanolind's Stovall No. 1, the epidote zone is absent but epidote-bearing sediments as represented in the Hornblende zone occur 1,800 feet below the *Bigenerina* sp. horizon.

Recent study has shown that in the parishes bordering the coast where faunal horizons above the *Discorbis* zone have been established, the base of the Epidote zone transgresses westward into older sediments. The transgression by the base of the Epidote zone coastward and westward into older sediments suggests that, at least in part, the epidote-bearing sediments, particularly in the coastal region of southern Louisiana, were transported from the west presumably by longshore currents.

The epidote assemblage is well represented at the surface outcrops. It has been observed in samples collected along outcrop sections I, II, III, and V. From the outcrop data it appears that the Epidote zone fingers out from the Colorado River drainage basin of Texas in the direction of Sabine Parish, Louisiana, and that the Epidote and Kyanite assemblages are each characteristic of a different distributive province. This fingering out toward the northeast of the Epidote zone in the outcropping formations supports the concept arrived at independently from subsurface studies, that the epidote-bearing sediments, particularly in the downdip region of southern Louisiana, were not all transported from the north, but may, in part, have come from the west or southwest.

Profiles of the Epidote zone (Figs. 2 and 3) show that in the subsurface sediments of southern Louisiana it is more than 1,000 feet thick. At the outcrop in Sabine Parish, Louisiana, the Epidote zone

[6]According to J. F. West, paleontologist, Shell Oil Company, Incorporated.

occupies a very thin stratigraphic interval. In Figure 3 the subsurface and surface data have been combined showing the Epidote zone wedging out up the dip. This apparent thinning toward the outcrop is explicable either as the consequence of an angular unconformity which truncates the Epidote zone or as a depositional feature.

As a depositional feature the wedge-shaped Epidote zone may be the consequence of normal basinward thickening of sedimentary deposits. The thickened, downdip, epidote-bearing, marine sediments could have been transported entirely from the north or in part from the east or west by longshore currents. However, the data with regard to the transgression of older sediments coastward and westward by the base of the Epidote zone suggest that a substantial part of the epidote-bearing sediments in the downdip region was transported from the west.

HORNBLENDE ZONE

The Hornblende zone of the subsurface sediments is known largely from wells in the coastal parishes of Louisiana. It is the youngest of the mineral zones described. Owing to the practice of not coring through the shallower strata, samples from the Hornblende zone were not available except from a few wells. Consequently, the regional relations of this zone to the underlying Epidote zone are not perfectly clear.

The base of the Hornblende zone is not an easily determined boundary. Strata characterized by the hornblende assemblage commonly occur intercalated between strata containing the epidote assemblage. (See the Shell's Realty Operators No. 1 and No. 1-B, Terrebonne Parish, Figs. 17, 18; the Continental's Hebert No. 1, Vermilion Parish, Fig. 11.) The writer has interpreted these intercalations as fingers extending laterally from the main body of the Hornblende zone. In the dip section (Fig. 2) the main body of the Hornblende zone is shown fingering out up the dip. The evidence for this is not indisputable but is suggestive of such an interpretation. In the Shell's Hebert No. 1 and the Stanolind's Stovall No. 1 of Vermilion Parish, abundant hornblende is present down to the very base of the Epidote zone. In these wells the Epidote zone, proper, is absent, and the Hornblende zone appears to contain a composite of the Epidote zone minerals and the Hornblende zone minerals. Farther up the dip in the Continental's Hebert No. 1, hornblende is comparatively rare, and only two stringers carrying hornblende occur in the lower 2,000 feet of the Epidote zone. In the Humble's Clayton No. 1, Jefferson Davis Parish, the lower 2,000 feet of the Epidote zone are free from hornblende, except for a few traces. Farther up the dip in the Gulf's Godet No. 2, St. Landry Parish, a stringer of hornblende occurs about

600 feet above the base of the Epidote zone, but the presence of this stringer so close to the base of the Epidote zone is probably the result of thinning of the latter over the prominent Port Barre dome. In the Humble's Haas No. 1 no hornblende occurs in the lower 1,800 feet of the Epidote zone.

In the outcropping formations examined, abundant hornblende was found only along outcrop section I which is in the drainage basin of the Colorado River of Texas. Here hornblende was found in parts of the Oakville, Lagarto, Lissie, and Beaumont formations. Hornblende was absent except for a few traces from these and other Cenozoic formations examined along the outcrop sections toward the north and east. The most likely source of the hornblende in the formations along section I is the Central Mineral region (Llano-Burnet uplift of central Texas) in which metamorphic and igneous rocks are exposed, and which is drained by the Colorado River. The Cenozoic formations along the outcrop sections farther north and east were probably derived from old sedimentary rocks deficient in hornblende.

The source of the hornblende in the subsurface formations of southern Louisiana is not definitely known. The outcrop data indicate that the Central Mineral region of Texas may have been a contributing source. Hornblende-bearing sediments derived from the Central Mineral region and deposited below the strand line along the Texas coast could have been transported eastward by longshore currents to the offshore, coastal region of Louisiana. However, the areal distribution of the outcropping formations studied is far too limited to permit a definite determination of the source of the hornblende in the Louisiana subsurface formations.

The outcrop sections studied and described are confined largely to Texas—only one from Louisiana having been here described. These sections across the outcrops of the Cenozoic strata occur at intervals along a line which roughly parallels the coast line and extends from the drainage basin of the Colorado River of Texas northeastward to the western region of Louisiana. The most easterly outcrop section described passes through Vernon and Sabine parishes of west-central Louisiana. In addition to the sections described, some samples were collected by T. L. Bailey, assisted by the writer, from outcrops of the Catahoula-Frio, Oakville, and Lagarto formations farther east in Grant and Rapides parishes of Louisiana, but no hornblende was encountered. Therefore, along this arcuate zone of outcropping Cenozoic formations extending from the Colorado River in Texas to central Louisiana, sediments containing abundant hornblende were found only in the drainage basin of the Colorado River.

George and Bay[7] studied the minerals from shallow core samples of the Catahoula formation in Covington County of south-central Mississippi and reported no hornblende in the heavy-mineral assemblages. They did not describe the minerals of the overlying Hattiesburg clay and Citronelle formation. In order to understand better the distribution of hornblende in the subsurface of southern Louisiana it will be necessary to complete the heavy-mineral study of post-Oligocene outcropping formations by extending the examination of outcrop sections through southeastern Louisiana and southern Mississippi.

From the evidence available at present, it is not possible to tell definitely what rôle the ancestral Mississippi River played in bringing hornblende-bearing sediments into southern Louisiana. It is known, however, from the work of Russell,[8] that the heavy-mineral assemblage carried by the present Mississippi River closely resembles that of the Hornblende zone observed in the subsurface. The time when the ancestral Mississippi first began to contribute hornblende to the Gulf Coast sediments has not yet been determined. Perhaps this can be established after the outcrops in southeastern Louisiana and southern Mississippi have been studied.

Recently the writer examined samples of sediment taken from the bottom of the Gulf of Mexico near the mouth of the Rio Grande. It is highly probable that the present bottom sediments of this region were carried into the Gulf of Mexico by the Rio Grande. These samples carry a mineral assemblage much like that of the Hornblende zone in the Louisiana subsurface.

The profile of the Hornblende zone fingering out up the dip from Vermilion Parish to St. Landry Parish and the distribution of hornblende in the outcropping formations—although knowledge of the latter is admittedly incomplete—suggest that the hornblende assemblage, unlike the kyanite assemblage, was not carried into southern Louisiana over a broad front from the north, but rather was swept along comparatively narrow channels into the Gulf, possibly by any or all of the following rivers, the ancestral Rio Grande, Colorado, and Mississippi, and was distributed laterally from the vicinity of the rivers' mouths by marine currents. If hornblende was contributed to southern Louisiana sediments from at least two of the sources suggested then it is likely that the base of the subsurface Hornblende zone is of variable age, unless hornblende-bearing rocks in the drainage basins of each river were uncovered contemporaneously.

[7] William O. George and Harry X. Bay, "Subsurface Data on Covington County, Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 8 (August, 1935), pp. 1148–61.

[8] R. D. Russell, "Mineral Composition of Mississippi River Sands," *Bull. Geol. Soc. America*, Vol. 48, No. 9 (September, 1937), pp. 1307–48.

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LOS BAJOS FAULT OF SOUTH TRINIDAD, B.W.I.[1]

C. C. WILSON[2]
Palo Seco, Trinidad, B.W.I.

ABSTRACT

The Los Bajos fault, of late Miocene or Pliocene age, cuts across the southwestern peninsula of Trinidad with a strike of about N. 70° W. from Point Ligoure on the western coast to the vicinity of Negra Point on the southern coast. In its western part the apparent downthrow is more than 10,000 feet toward the south and in its eastern part there is an apparent downthrow of 7,000 feet toward the north. The writer believes this fault to be essentially a strike-slip fault with the northern side moving eastward relative to the southern side and the apparent throw at the fault line resulting from the discordant juxtaposition along the fault of folded structures developed previous to and during the fault movement. In the western part of its course the differential horizontal movement amounts to as much as 7 miles. The fault has played a major rôle in influencing the migration and accumulation of oil and its course intersects several major oil fields. The origin of this fault is explained by the writer as due either to (1) "gravity collapse" of incompetent sedimentary filling of the Orinoco basin, or (2) crustal adjustment related to drift movement of the American continents.

INTRODUCTION

A brief glance at the geological map of Trinidad (Fig. 1) will reveal the geographical position of the Los Bajos fault. It traverses the southwestern peninsula of the island, from the north side of Point Ligoure on the west coast to a point about one mile west of Negra Point at almost the middle point on the south coast, and maintains an approximately straight course on an azimuth of 112° from true north. The lateral extent of the fault offshore from the island is completely unknown. Northwestward, the only land which occurs on this azimuth is the narrow northern range at Carupano in Venezuela. Southeastward, the direction of the fault extends out into the Atlantic along a line parallel with the northeastern edge of the Guayanas.

Its course, within the island of Trinidad, intersects various oil-field areas, including (starting from the west coast) the Point Fortin fields (West, Central, and East), the Los Bajos field, and the Coora-Morne Diablo field.

The Los Bajos fault does not appear on Waring's[3] map, neither does it appear on any of the previously published geological maps. However, in the last decade a steady advance has been made in knowledge of the oil-field geology of Trinidad and, in addition to the surface mapping, drilling in the neighborhood of the Los Bajos fault, assisted by up-to-date logging of wells and their interpretation, has

[1] Read before the Trinidad Geological Conference, Port-of-Spain, April, 1939. Manuscript received, June 28, 1940. Published by permission of the Trinidad Petroleum Development Company, Ltd.

[2] Resident geologist, Trinidad Petroleum Development Company, Ltd.

[3] Gerald A. Waring, "The Geology of the Island of Trinidad," *The Johns Hopkins Univ. Studies in Geology No. 7* (1926).

now shown not only that the fault exists but that the fault occupies a position of very great importance by reason of its relation to oil migration and accumulation.

TABLE I*

STRATIGRAPHIC COLUMN OF YOUNG TERTIARY DEPOSITS IN MAIN OIL FIELDS, SOUTHWEST TRINIDAD

(Compiled by K. Schmidt)†

Series	*Formation*		*Suite*	
Pliocene	La Brea		La Brea sands, silts, clays, and porcellanite	Sheet sand deposits
∼∼∼∼∼∼	∼∼∼∼∼∼∼∼∼∼∼		∼∼∼ *Unconformity* ∼∼∼	
Miocene	Morne l'Enfer	Upper	Upper Morne l'Enfer sands, silts, and clays	
			Lot 7 silt (marker at base)	
		Lower	Lower Morne l'Enfer sands, silts, and clays	
	∼∼∼∼∼∼∼∼∼∼∼		∼∼∼ *Unconformity* ∼∼∼	
	Forest	Upper	Forest silts	Highly lenticular deposits
			Upper Forest clay	
		Lower	Forest sands	
			Lower Forest clay or intermediate clay (marker at base)	
	Cruse		Upper, middle, and lower Cruse sands, silts, and clays	
	Palo Seco		Clays, including *Sphaeroidinella* clay and Herrera conglomerate	
∼∼∼∼∼∼	∼*Angular unconformity*		∼∼∼∼∼∼∼∼∼∼∼∼	
Oligocene	Alley Creek—Princes Town marls			

* Presented at the Trinidad Geological Conference, Port-of-Spain, April, 1939.

† K. Schmidt, palaeontologist, Trinidad Leaseholds, Ltd., Pointe-a-Pierre, Trinidad, B.W.I.

STRUCTURES IN CONTACT ON SIDES OF FAULT

In its western section, the Los Bajos fault separates the deepest part of the Erin basin from the highest part of the Point Fortin structure. The Point Fortin structure may be regarded mainly as a north-dipping flank extending parallel with the Los Bajos fault east-southeast for about 5 miles, as far as the point of contact between the fault and the axis of Fyzabad anticline which strikes at N. 65–70° E.

At Point Ligoure, the apparent vertical displacement of the fault amounts to 10,000 feet with an apparent downthrow toward the south.

Fig. 1

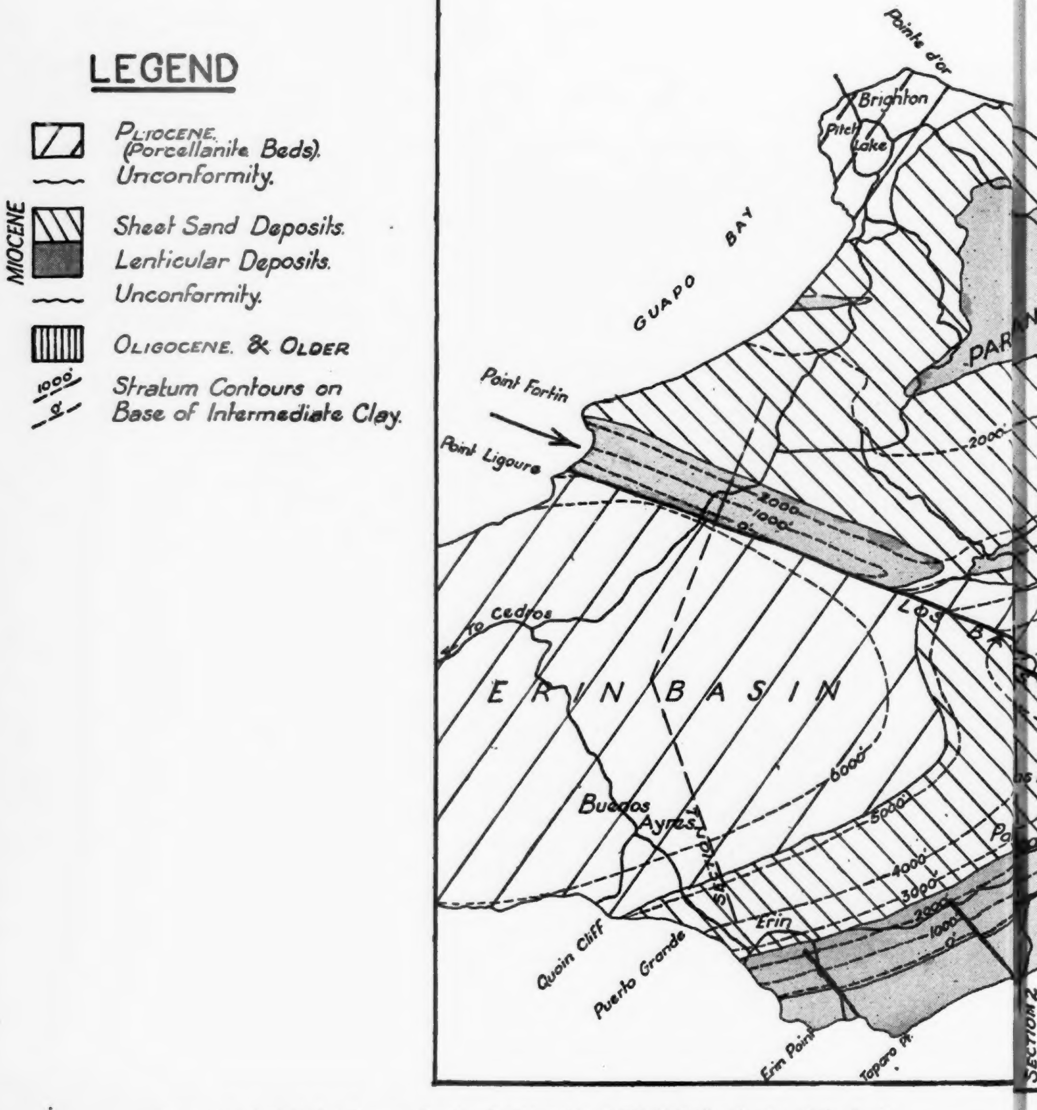
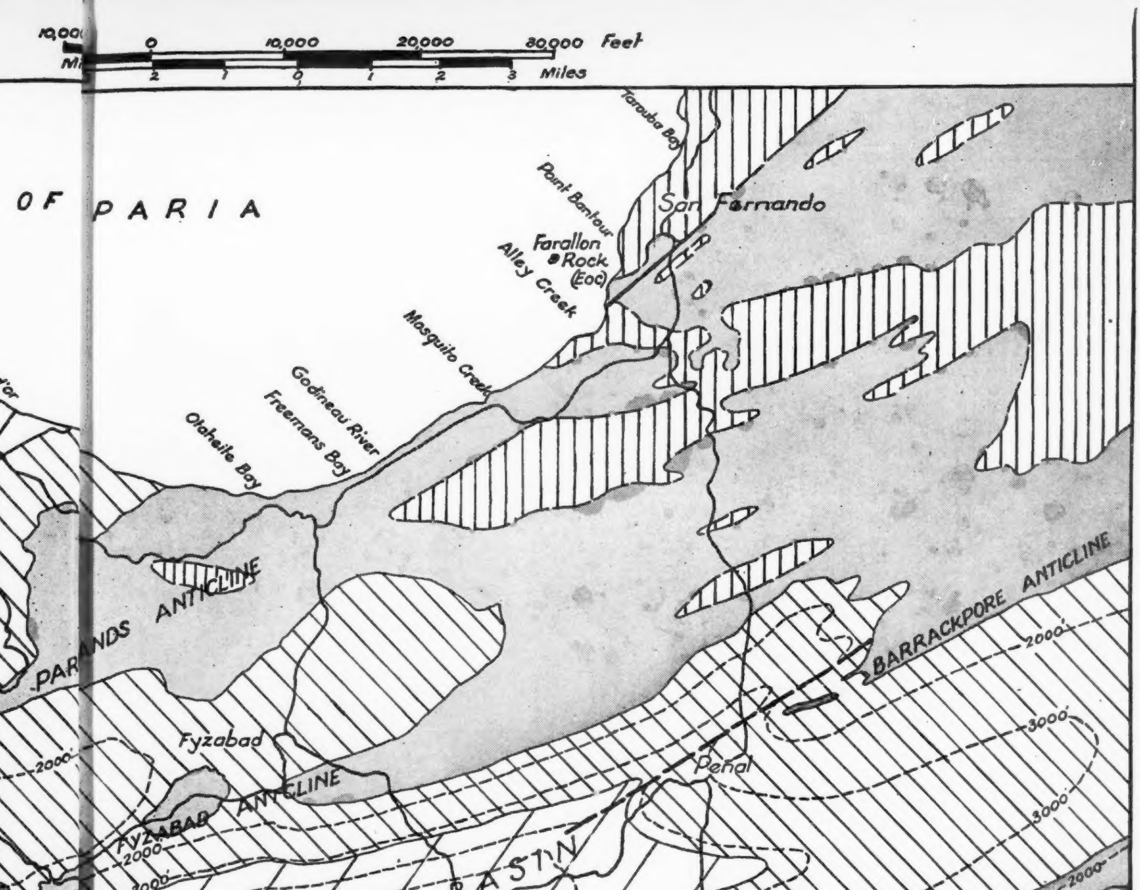


FIG. 1.—Geological sketch map of main oil-field region of Trinidad showing Los Bajos fault.



0
10,000
20,000
30,000 Feet
2
1
0
1
2
3 Miles
OF PARIA
Tarouba Bay
Point Bontour
San Fernando
Farallon Rock (Eoc)
Alley Creek
Mosquito Creek
Godineau River
Freemans Bay
Otaheite Bay
PARANDS ANTICLINE
BARRACKPORE ANTICLINE
Fyzabad
FYZABAD ANTICLINE
Penal
SIPARIA BASIN
Siparia
Rock Dome
Morne Diablo
MAIN SOUTHERN ANTICLINE
Coora
FAULT
Santa Flora
Los Bajos
MAIN SOUTHERN ANTICLINE
Moruga Hills
Direction of Horizontal Shift
Negra Point
SECTION 2
Palo Saco Bay
SECTION 3 Chagonary Pt.
Quinam Bay SECTION 4
C.C. Wilson - 1939.

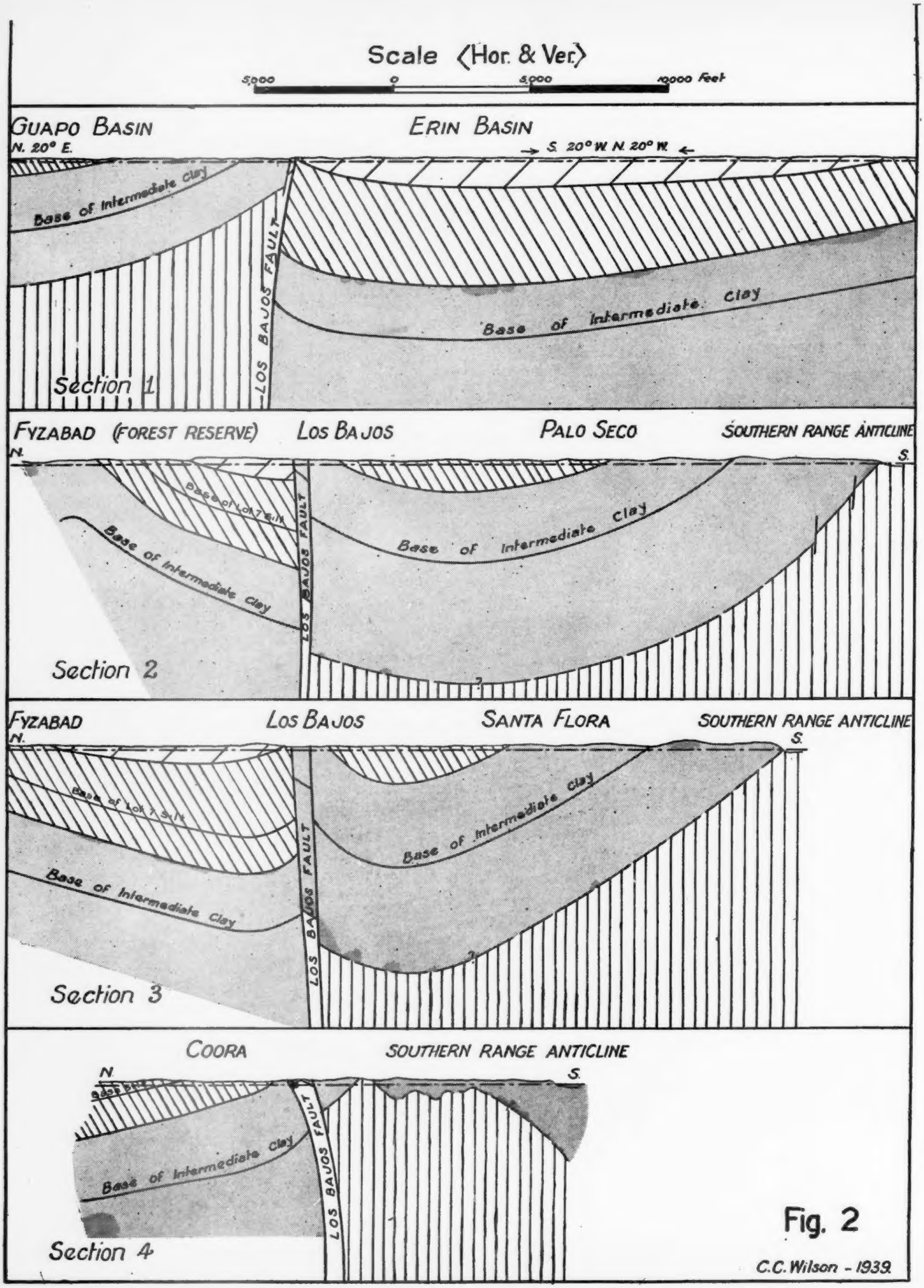


FIG. 2.—Vertical sections across Los Bajos fault. Legend as in Figure 1.

Eastward, this throw diminishes only slightly toward the eastern end of the Point Fortin structure (Section 1, Fig. 2) but, beyond the contact with the axis of the Fyzabad anticline, the throw of the Los Bajos fault vanishes in a distance of only one mile. Continuing eastward, the displacement reappears and with similar rapidity develops an apparently vertical throw of 4,000 feet at Los Bajos, here the downthrow being toward the north and not, as at Point Ligoure, toward the south.

A complete reversal of the conditions described west of Los Bajos occurs in the area between the oil fields of Los Bajos and Coora-Morne Diablo. Here, the axis of the Siparia syncline is brought into contact from the north at the fault with the Los Bajos structure. The Los Bajos structure, like that of Point Fortin, is a monocline parallel with the Los Bajos fault between Los Bajos and Coora (as a horst in its highest portions) and generally dipping away from the fault. A gently folded nose, however, plunges westward from the Los Bajos structure where it leaves the fault and enters the Erin basin.

Within the Coora-Morne Diablo region, the Los Bajos structure diminishes as the fault intersects, diagonally, the north flank of the Southern Range anticline. Within the shattered crestal zone, evidence of major faulting becomes extremely indefinite beyond the fact that the axis of the main structure veers from the characteristic strike of N. 65–70° E. to approximately E.-W. in that region, shows an eastward displacement, and finally returns to the N. 65–70° E. strike in the direction of the Rock Dome area on the east.

Age of Fault

The unconformable base of the Porcellanite beds (correlated as uppermost Miocene or early Pliocene) is displaced vertically by at least 1,000 feet in western Los Bajos. It has been considered that the upper Porcellanite beds were proportionately less affected by the fault than were the lower Porcellanites and the lower Porcellanites were in turn less affected than older beds. It appears from this that faulting actually began at the commencement of the orogenic movement.

The apparent vertical movement of the unconformity is less than that of the Lot 7 silt, but beds below the Lot 7 silt all show the maximum vertical displacement. Therefore, the writer is inclined to the view that the fault movement was initiated at a time not earlier than upper Miocene.

It is clear, as shown in Section 2 (Fig. 2) of the south flank of the Fyzabad anticline, that the late Miocene-Pliocene folding movement began soon after the deposition of the Lot 7 silt. This is admirably

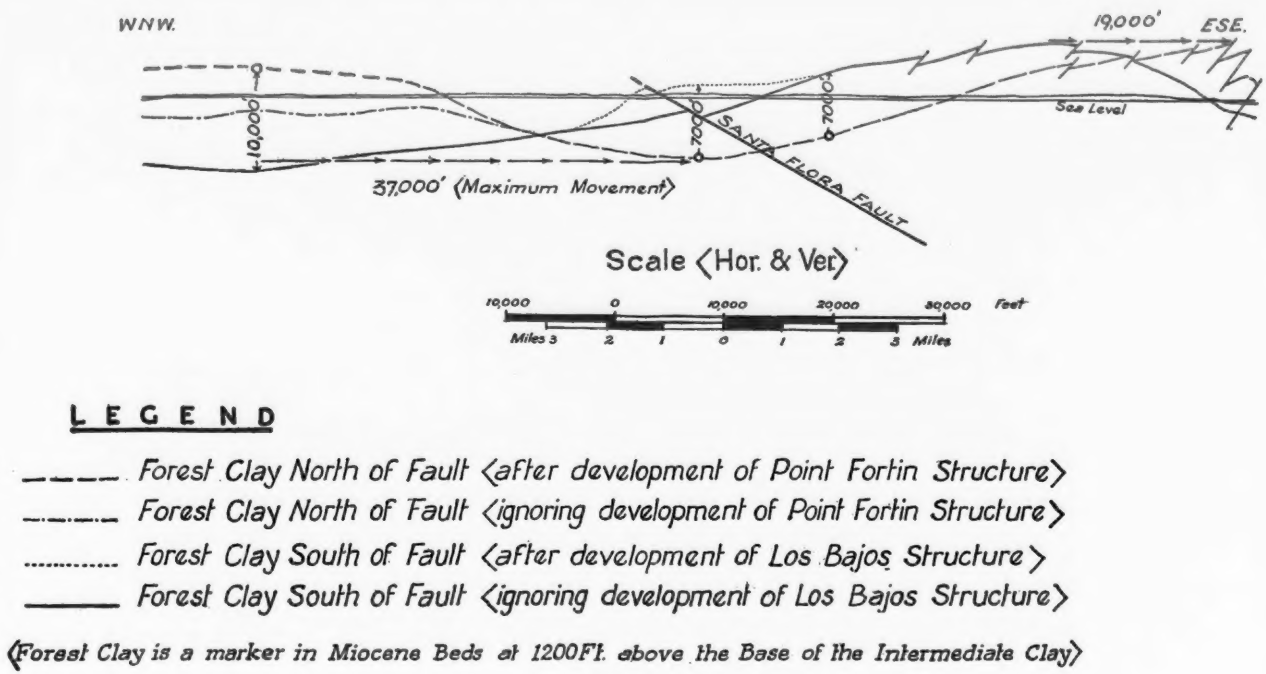


FIG. 3.—Section along Los Bajos fault.

demonstrated by the downdip thickening of all beds above the Lot 7 silt. The extent of folding shown in this section as measured by the gradual angularity between the Lot 7 silt and the Porcellanite beds amounts to 20°. Folding continued after the deposition of the Porcellanite beds as may be seen in the Puerto Grande-Buenos Aires region where dips up to 30° occur in the Porcellanite quarries themselves.

Correlation of the base of the Porcellanite beds on the two sides of the Los Bajos fault has not yet been definitely established, plant remains being the only fossils found so far in these beds. Fossil evidence, also, in the Morne l'Enfer beds, is likewise only represented by plant remains and no differentiation can be drawn between these beds. It is, therefore, possible that the unconformity mapped on the surface to the west of Los Bajos and south of the fault may have developed appreciably later than the assumed base of the Porcellanite beds found on the south flank of the Fyzabad anticline (Section 3, Fig. 2).

One must, therefore, allow for the possibility that the Los Bajos fault took place in Pliocene or later time and was entirely subsequent to the folding movement of upper Miocene-Pliocene age.

Theories Relating to Mechanics of Los Bajos Fault

Figure 3 is a diagram drawn to scale to show the relative positions of the base of the Forest clay on the two sides of the fault. The Forest clay is the highest pure clay member of the Forest-Cruse sequence of alternating estuarine and shallow-water marine sands, silts, and clays, generally named the *Cyclammina* clays, which contain a strongly arenaceous foraminiferal fauna. On the section an attempt has been made to represent, by unbroken lines, the structural position of the Forest clay as it would have existed had the fault structures of Point Fortin and Los Bajos not been developed. This addition is made on the assumption that these two structures were developed not as part of the upper Miocene-Pliocene folding movement but merely due to compression between the two sides of the fault during its movement, and the writer has tried to represent the two sides of the fault before faulting took place.

THEORY OF VERTICAL DISPLACEMENT

Most of the previous observers have maintained that the fault, even with this great variety of throw and complete dissimilarity of sediments between the two sides, has taken place in a vertical or rotational sense only, and have considered that the fault is a steep reversed fault, slightly overthrust from the north at Point Fortin and slightly underthrust toward the south at Los Bajos and Coora.

This explanation involves an exceptional type of scissor- or hinge-fault mechanism, with a pivot at the point of zero displacement between Point Fortin east and Los Bajos. One would expect, therefore, to find at this pivot some cause for rigidity which might be due to the existence of a topographic "high" in the surface of the basement rocks in this vicinity. No evidence of such a "high" has yet been found. Drilling is now being carried out near this pivot and no evidence of strong unconformity has yet been recorded. It is very exceptional, too, that with such diversity of throw the fault maintains such a straight path at outcrop.

The strike of folding and fracture related to the Los Bajos fault is distinct from the N. 65–70° E. strike of folding found elsewhere to be characteristic in the southern and central parts of the island. Further, the Los Bajos fault system completely terminates any structural features which approach the fault from either side. The main Fyzabad anticline, as mentioned previously, is cut off abruptly at the fault and no continuation southwestward can be identified whatsoever. There is no downthrown flank south of the Point Fortin structure; neither is there any downthrown flank north of Los Bajos.

THEORY OF HORIZONTAL-SHIFT FAULTING

Lack of structural relationship between the two sides of the fault means either that the fault occurred previous to the development of the Fyzabad structure, which seems unlikely (because the unconformity at the base of the Porcellanites shows only a low angularity and because Porcellanite beds, which themselves were faulted, were deposited after the main folding had taken place), or, alternatively, that the fault is a horizontal-shift fault, having been the result mainly of horizontal displacement after the folding movement had occurred, and was not the result of the exceptional hinge movement previously suggested. Now, if the region north of the fault has so moved, horizontally from west to east, in relation to the region south of the fault, then one should find southern counterparts of the various displaced structures of the region north of the fault. These are indicated as follows.

1. The two main basins in southern Trinidad are the Erin basin and the Siparia basin, and they are separated by the Los Bajos fault. These two basins were, in the writer's opinion, developed as one continuous unit and received sediments from the same source, but now their deepest regions in contact with the fault are separated, that of the Siparia basin being considerably to the east of the deepest part of the Erin basin.

2. Each of these basins is bounded on the south by similar segments of the Southern Range uplift.

3. The Siparia basin is bounded on the north by the Fyzabad anticline. The counterpart of the Fyzabad anticline may be the Point Ligoure structure which is represented within the island by only a small triangular patch of land south of the fault at Point Ligoure and carries well defined dips toward the southeast. The writer considers that this direction of dip is important, because, being oblique to the fault, it suggests that these dips are not entirely due to fault drag and, further, because they are parallel with those dips of the south flank of the Fyzabad anticline. In other words, the Point Ligoure flank may actually be the south flank of a major structure which was cut by the fault and the northeastern extension was moved eastward by the fault movement to become the Fyzabad anticline.

4. The two structures parallel with the fault, namely, the Point Fortin structure and the Los Bajos structure, may have been developed entirely by a component normal to the fault, of the stresses in operation, which are supposed to have developed at right angles to the strike of the Northern Range. These structures, therefore, were formed during the faulting movement and may have resulted from variations from the straight in the original direction of the fracture plane.

VISIBLE EVIDENCE OF LATERAL MOVEMENT

F. W. Rohwer[4] brought to the writer's notice the fact that nearly horizontal slickensiding was visible at Point Ligoure.

The writer wishes to express his thanks to A. G. Hutchison[5] for a core sample (Fig. 4) from a well drilled during December, 1939, through the Los Bajos fault at a point near the junction between the Point Fortin structure and the Fyzabad structure. Horizontal slickensiding is very clearly demonstrated in this sample, and it is understood that evidence of similar movement was repeatedly shown through 1,500 feet of beds where the Los Bajos fault zone, hading north, was penetrated by the well at a high angle.

A. J. Goodman[6] informs the writer that at La Lune Point (slightly east of Negra Point on the south coast) there is a fault revealed in the beach section with the ends of the beds on either side dragged parallel with the fault and facing opposite directions. It has all the appearances of strike slip but is presumably on a smaller scale than the Los Bajos dislocation.

2. North of the Los Bajos fault, upper Morne l'Enfer beds consist mainly of sands with fresh and brackish water. South of the fault, a

[4] Chief geologist, Antilles Petroleum Company (Trinidad), Limited.

[5] Chief geologist, United British Oilfields of Trinidad, Ltd., Point Fortin, Trinidad.

[6] Chief geologist, Cory Brothers, Ltd.

fresh-water sand development has only been observed in the western part of the Palo Seco oil field where it exactly resembles contemporaneous sediments at Coora. Eastward, in the southern fault block, these fresh-water sands gradually change to clays. It has been suggested that a bar, formed during the deposition of these beds, may have separated, along the fault, sand deposition from clay deposition. It is

FIG. 4.—Horizontal slickensiding (at right angles to long axis of core) in core from well drilled through Los Bajos fault. Natural size.

considered that such a persistent bar, continually developing during the deposition of at least 2,500 feet of sediments along a line coincident with the Los Bajos fault at Los Bajos, would be exceptional. It seems preferable to think that the change from sand to clay, developing from west to east in the Palo Seco field, was moved eastward, north of the fault, to somewhere in Morne Diablo by horizontal-shift faulting (Fig. 3).

3. A much closer resemblance occurs between sedimentation at

Coora and western Palo Seco than between either of these localities and Fyzabad.

4. The abrupt differences in thickness and sand content of beds now in contact at the Los Bajos fault (see the various sections, especially Sections 2 and 3, Fig. 2) accompanied by a steady increase in thickness southward, both between the Lot 7 silt and the top of the Cruse and between the top of the Cruse and the base of the Miocene, offer very strong evidence that lateral rather than vertical movement has taken place to form the Los Bajos fault.

SANTA FLORA TENSION FAULT

In the area immediately east of the Palo Seco field, an area known as the Santa Flora region, a large fault block occurs downthrown about 1,000 feet in relation to the Palo Seco north flank and to the south flank of the Los Bajos structure on the north.

This fault, separating Palo Seco from Santa Flora (now named the Santa Flora fault) appears to be a normal fault which hades eastward at an angle of nearly 60° from the vertical (it dips east at only 30°).

The crestal zone of the Palo Seco structure (Southern Range anticline) was apparently not displaced laterally by the Santa Flora fault.

A fault of this nature can only have been formed under lateral east-west tension and this evidence is advanced for horizontal movement along the Los Bajos fault as opposed to vertical movement.

Thus, a bulge northward must have occurred on the line of weakness along which the Los Bajos fault developed. This bulge occurred on the northern edge of the Santa Flora fault block.

It is along this edge that the Los Bajos structure attains its greatest disturbance. In addition, beds north of the fault along this edge show steep folding which does not occur west of the contact between the Santa Flora fault and the Los Bajos fault.

The writer suggests that this bulge formed a zone of resistance to the horizontal movement of the Los Bajos fault and was subsequently smoothed out laterally by folding on both sides of the fault causing drag which, in the Santa Flora area, resulted in tensile stresses acting in an easterly direction and which finally obtained release by movement down to the east on the plane of the Santa Flora fault.

In the writer's opinion, it is easier to conceive such a cause for the existing structural features than to interpret these features by vertical displacement of the Los Bajos fault with underthrusting of the Los Bajos structure by the Siparia syncline.

Underthrusting of the Los Bajos structure (which, incidentally,

here shows horsting parallel with the Los Bajos fault) would surely tend to raise rather than to depress the Santa Flora area in relation to the Palo Seco sector.

Although the axis of the Southern Range anticline (northeast of the fault) has not been displaced so far laterally from its southwest counterpart as has the Siparia syncline from the Erin syncline, a sufficient similarity occurs between the two sides of the fault to make the horizontal-shift fault theory more acceptable than the theory of scissor action.

It is thought that, in the soft incompetent beds such as those which are in contact from end to end of the Los Bajos fault, vertical displacement at the fault would show far greater disturbance than has, so far, been found. The absence of shattering between the two sides of the fault at Los Bajos and the confinement of the fault to a single plane where an apparent throw of 4,000 feet occurs, is strong evidence in favor of horizontal-shift faulting.

With regard to horizontal displacement, it seems that, once the fracture has developed, no further major deformity will occur unless the fracture is not straight. Where not straight, the movement will tend to plane off any protuberances and will there cause local contortion.

Theory of Folding and Subsequent Faulting

Evidence is by no means sufficiently complete to allow the establishment of any conclusive theories regarding the cause of horizontal-shift faulting on this scale. However, two alternative suggestions are presented. 1. Superficial gravity collapse of sediments in a south-of-easterly direction over the metamorphic basement may be due to southeastward tilt of the earth's crust and governed by relative competence of mainly Tertiary beds. In this theory, it is suggested that the fault may be the dividing line between beds on the northeast, which have a greater tendency to flow, and beds on the southwest, which show a certain rigidity.

2. Horizontal-shift faulting may be due to a much more deep-seated cause, arising from the tectonic stresses which resulted in the last orogenic movement of the Caribbean region. Hess,[7] in his latest publication, describes an eastward movement of Haiti, in relation to Cuba, of more than 60 miles due to a north-south compression of the Caribbean region, which found release of stress by movement toward the Atlantic. The Los Bajos fault may conceivably have occurred as

[7] H. H. Hess, "Geological Interpretation of Data Collected on Cruise of U.S.S. *Baracuda* in the West Indies," *Trans. Geophysical Union* (1937); and "Gravity Anomalies in Island Arc Structures with Special Reference to the West Indies," *ibid.* (1938).

a similar but later release of stress on the south side of the Antillean arc (Fig. 8).

GRAVITY COLLAPSE OF NORMAL SEDIMENTS DUE TO SOUTHEASTWARD TILT OF EARTH'S CRUST

Accepting Haarmann's[8] theory of orogenesis or the gravitational-folding theory of Jefferys,[9] it may be assumed here that the earth's crust was elevated due to a swelling of the sial in the region of the Miocene land of Antillia and that structures were formed subsequently toward the basin between this land and the Guayana shield. These structures were formed by a southward slumping, under gravity, of sediments from off a part of this Antillean uplift, and these sediments slipped southward over the metamorphic basement rocks, lubricated by incompetent clays, possibly wetted with oil, gas, and salt water.

The structures that were developed in the south of Trinidad comprised the Southern Range anticline with its complementary syncline on the north, including both the Erin and Siparia basins as one unit.

After the orogenic movement had reached its greatest elevation and the foothill folding in central and southern Trinidad were nearly complete, later minor adjustments of equilibrium followed.

J. V. Harrison and N. L. Falcon[10] describe a number of overturned and recumbent folds on the flanks of gentle, broad, symmetrical structures in Iran. They explain these anomalous flanking structures as actually being formed on the flanks of main anticlines due to gravity collapse after the development of topographic gradients sufficiently steep to allow downward movement. They write as follows.

> Thus it sometimes happens that, when a limestone sheet which appears to be massive and robust is uncovered . . . , it may not be able to retain its simple form, but wrinkles by slipping over a lubricant, the zone of marls below. The action seems to take place without the intervention of water, . . . and the marls are so calcareous that they resist the puddling action of water. The dry marls appear to be sufficiently slippery to allow the limestone sheets to move over them.

In Trinidad, Oligocene and Miocene sediments, north of the Los Bajos fault, are exceptionally incompetent; far more incompetent, it is believed, than their more arenaceous lateral equivalents in the Orinoco basin. In the area north of a line joining the Pitch Lake to

[8] E. Haarmann, *Die Oszillations Theorie.* Published by Ferdinand Enke, Stuttgart (1930).

[9] H. Jefferys, "Mechanics of Mountains," *Quar. Jour. Geol. Soc. London,* Vol. 82, No. 346 (Part 2 for 1931), pp. iii, iv.

[10] J. V. Harrison and N. L. Falcon, "Gravity Collapse Structures and Mountain Ranges as Exemplified in South-west Iran," *Quar. Jour. Geol. Soc. London,* No. 365 (June 26, 1935).

Morne Diablo, these beds may be regarded as approaching fluidity and would require much smaller topographical gradients than those which were responsible for forming gravity-collapse structures described by Harrison and Falcon.

An example of slumping has been demonstrated at various points near the south coast of Trinidad where overburdens of incompetent recently ejected mud-flow material have slipped downhill toward the sea. These slump features are believed to represent in miniature what

FIG. 5.—View of tension near highest point of slumped mud-flow body.

actually may have occurred on a much larger scale during major mountain-building movements.

In the case of these mud-flow deposits, equilibrium is upset, naturally, by repeated ejections of mud which appreciably elevate the surface. Along the south coast of Trinidad, particularly in the Cedros area, recent slump features are intensified by the fact that incompetent recent deposits attain great thickness at only a short distance offshore toward the south. Slumping, therefore, is due not merely to the tendency to reach sea-level, but to slide still deeper into the incompetent beds under the sea.

An outstanding example of slumping took place in September, 1935, in the l'Envieuse Estate at Cedros and was examined by the writer. A body of mud-flow about ½ mile in length by ¼ mile in breadth

Fig. 6.—View of apparent overthrust on western edge of slumped mass. Movement was not felt in house on left.

Fig. 7.—Nearer view of Figure 6, showing slickensiding parallel with surface.

moved southeast about 10 feet laterally along a slope only 2° from the horizontal. This movement took place abruptly during the night and was not felt by local inhabitants.

The moved block was bounded by a magnificently slickensided shear plane standing nearly vertical and showing striations exactly parallel with the surface.

The similarity of this shear to that of the Los Bajos fault lies in the fact that where the shear plane travelled along the contour of a slope tilted either toward or away from the area moved, the shear plane showed a slight apparent overthrust toward the lower ground. This overthrust, of course, was not compressional and in some places showed a deep open crack nearly 2 feet wide at the surface.

Compressional features were clearly evident in the frontal part of the slump, where the beach sand maintained, for a short period, beautiful low-angle thrusts at less than 45° from the horizontal, pointing out to sea.

SOUTHWARD GRADIENT FORMED BY THE MIO-PLIOCENE OROGENY

Having satisfied oneself with the extreme incompetence of beds in Trinidad, one must now look for a gradient sufficiently steep to cause these beds and their overburden to wrinkle southward and, by differential rock strength, to cause horizontal-shift faulting. Various authorities give evidence for assuming that a slight tilting actually was developed by the last main orogenic movement.

H. von Ihering[11] gives definite paleontological evidence that a land bridge between Brazil and Africa existed until the Miocene, but that, in late Miocene time, this bridge subsided beneath the Atlantic.

J. W. Gregory,[12] using G. A. Waring's evidence of the age of folding in Trinidad, considers that the last land bridge across the Atlantic subsided after the Miocene period.

H. Gerth[13] states: " . . . for the first time (at the end of Lower Cretaceous) in Eastern Brazil, transgressions of the Atlantic Ocean, which now separates South America from Africa, occurred over large areas . . . "; again he mentioned: "On the south (i.e. of the Cretaceous sedimentary basin of Venezuela) the basin was limited by a more extended ancient nucleus of Guayana" (than at the present day), and, in conclusion, he considered that "the sediments in this geosyncline are folded between two old masses, one in the South, which is subsiding slowly, and the other in the North which is rising and pushing those sediments, in the basin, towards the South." He gives one the

[11] H. von Ihering, "Land Bridges across the Atlantic and Pacific Oceans during the Kainozoic Era," *Quar. Jour. Geol. Soc. London*, No. 347 (June 11, 1930).

[12] J. W. Gregory, "The Geological History of the Atlantic Ocean," *ibid.*, Vol. 85, No. 338 (Part 2 for 1929), p. cii.

[13] H. Gerth, "General Outline of the Geological History of the South American Continent." 2nd Venezuelan Geological Congress, April, 1938.

impression that part of the ancient land mass of Guayana is still subsiding. J. A. Bullbrook,[14] a geologist, considers that certain embayments in the Guayana front (British Guayana) definitely suggest recent subsidence of the continental shelf. Grantham and Noel Paton[15] mention the subsidence of basement rocks in the basin of the Berbice River, and state that Pleistocene or upper Pliocene beds in that basin are known to be at least 1,680 feet thick and suggest that the basement rocks may even, in some regions, have subsided to depths greater than 3,000 feet. The writer suggests that the Guayana region bounded on the south by the Amazon and on the north by the Orinoco must be affected by the vast sedimentation which has been and is still being developed by those tremendous sources of material. Marine currents deflect the supply of material brought down by the Amazon, so that they come to rest in front of the present Guayana coast and may be contributing to recent subsidence of the eastern sector of the Guayana shield. The Orinoco may be causing similar subsidence of beds southeast of Trinidad and may be contributing to the development of regional subsidence of the eastern part of the Guayana shield. It is possible that this subsidence of the eastern edge of the Guayana shield may have provided a southward gradient sufficiently great to upset the state of equilibrium obtained after the late Miocene orogenic movement and resulted in the formation of structures by gravity collapse, terminating finally in the development of the horizontal-shift movement represented particularly by the Los Bajos fault.

RELATIVE COMPETENCE OF BEDS

An important factor which may have been responsible, in no small degree, for the development of horizontal-shift faulting instead of further folding is the appreciable increase of competence in lower Miocene beds in a southwesterly direction. A straight line between the Pitch Lake and Morne Diablo (parallel, incidentally, with the Los Bajos fault) separates generally arenaceous lower Miocene beds on the south from almost entirely argillaceous lower Miocene beds on the north where deeper-water marine conditions prevailed.

On the north, drilling in these beds and in the underlying Oligocene beds has encountered considerable difficulty in penetrating great thicknesses of caving shales.

Northeast of this line, folding appears to be more intense than in the area on the southwest. Northeast of this line, the Parrylands and

[14] Oral communications.

[15] D. R. Grantham and R. Noel Paton, *Geology of the Superficial Deposits of British Guiana* (1937). Report loaned to the writer by H. G. Kugler, chief geologist, Trinidad Leaseholds, Ltd., Pointe-a-Pierre.

Fyzabad structures rise and enter the Naparima area and therein show considerably more complex structural features. In addition, the Penal-Barrackpore fold has developed on the north flank of the Southern basin and, similarly, the Rock Dome structure has developed on the southern flank of the same Southern syncline. These two structures plunge and disappear toward the west-southwest. The Southern basin, in that eastern area, is not such a broad, gently warped syncline as that developed farther west.

The writer suggests that this decrease in the intensity of folding southwestward owes its origin to greater competence of beds in that direction. Competence of Miocene beds naturally is due to a southward and southwestward change from marine clays and soft marls to estuarine and shallow-water marine deposition of sands and silts laid down progressively nearer to the shoreline of the Guayana shield.

Evidence provided by mud-flow phenomena and, in some places, by wells which have penetrated pre-Miocene beds in the oil-field area tends to show that the Oligocene beds are still highly incompetent even southwest of the line joining the Pitch Lake to Morne Diablo. It may be that, northeast of the Los Bajos fault, incompetent Oligocene beds have formed lubricated soles for the slipping southeastward of Miocene and later deposits. Southwest of the Los Bajos fault, rigidity has been maintained more effectively by (1) greater competence of beds of either Miocene or Oligocene age, and (2) less subsidence of the western part of the Guayana shield than of that eastern part which, in Miocene time, showed definite submergence according to von Ihering (mentioned previously).

APPARENT REVERSED FAULTING

The two fault structures, the Point Fortin structure and the Los Bajos structure which are adjacent to the fault on its north side and on its south side, respectively, resulted, in the writer's opinion, from a component of the orogenic stress radiating from the main uplift in the north, acting normally to the plane of the Los Bajos fault. These structures grew most probably during the movement southeastward of the northern unit and were influenced, as previously suggested, by irregularities in the alignment of the Los Bajos fault. That southeastward movement took place presumably under the pressure of a second component of the stress radiating from the uplift in the north acting parallel with the fault plane.

Gravitational sliding of sediments (Haarmann's theory), therefore, may have been responsible for the horizontal-shift faulting movement occurring outward from an orogenic uplift which rose to a maxi-

mum along a roughly east-west band north of the island, together with a contemporary subsidence in the southeast which increased eastward of the existing Guayana shield.

Accompanying this argument, the writer contends that an increase in thickness and competence of Tertiary beds southwestward controlled, to some extent, the direction of sliding. The predominance of competent sands in the deposits which form the Moruga and Guayaguayare hills may have formed a buttress against which the Southern Range anticline was folded and thrusted and may, indeed, have partially obstructed the movement, southeastward, of the Los Bajos fault.

The frontal sector of the Los Bajos fault movement may be completely explained by similar thrusting on the highest structural point of the Southern Range anticline in the Rock Dome district (Marac Quarry) where Eocene beds are exposed.[16] It is not yet known whether this Eocene at Marac is in its original position or whether it forms a pinched block carried upward by folding of an imbricate nature into contact with younger beds. It is possible, however, that resistant monadnocks of Eocene or older beds, which formed islands during Miocene and Oligocene deposition, may later have formed a barrier which was sufficiently strong to prevent the sliding movement from passing east-southeast beyond the main anticline. Southeast of the main fold, Miocene beds suddenly become competent again, being, locally, predominantly sandy, and form a steep though rigid south flank. Faulting seen in the middle of the south coast may, therefore, be a quite unimportant relic of the horizontal-shift faulting movement, the main movement having been dispersed as thrusting on the north flank of the main anticline.

CONTINENTAL DRIFT IN APPROACH, ONE TOWARD OTHER, OF AMERICAN CONTINENTS AS CAUSE OF HORIZONTAL SHIFT FAULTING

The structure of the Caribbean region, according to Hess,[17] (Fig. 8) suggests a north-south contraction accompanied by a release of pressure eastward toward the Atlantic Ocean. Hess[18] suggests that release of pressure has not only been demonstrated along the Antillean

[16] H. G. Kugler, "The Eocene of the Soldado Rock near Trinidad," *Boletin de Geologia y Mineria, Ministerio de Fomento, Venezuela*, Vol. II, Nos. 2, 3, and 4, pp. 202–25.

[17] H. H. Hess, *op. cit.*, "Geological Interpretation of Data Collected on Cruise of U. S. S. *Baracuda* in the West Indies," *Trans. Geophysical Union* (1937).

[18] H. H. Hess, "Gravity Anomalies in Island Arc Structures with Special Reference to the West Indies," *ibid.* (1938).

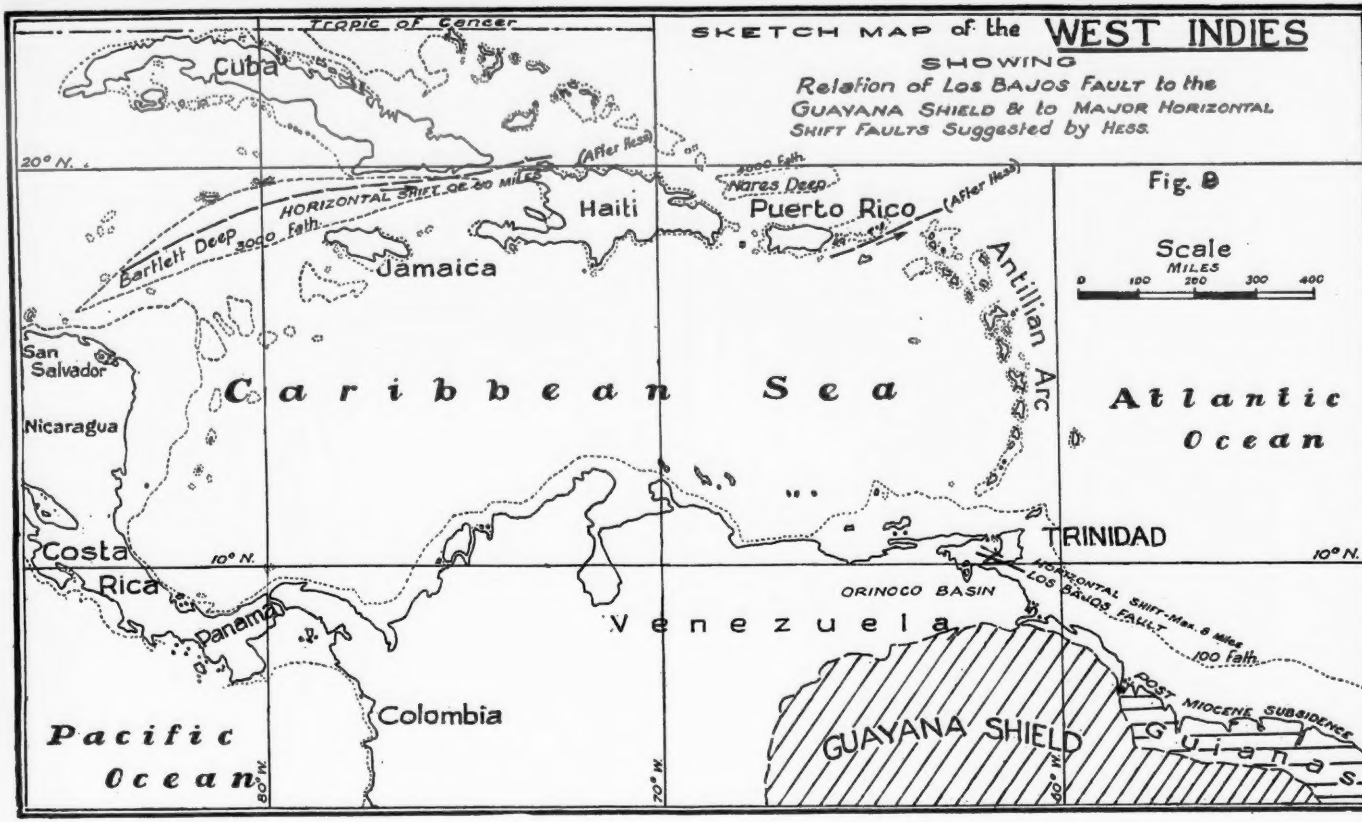


FIG. 8.—Sketch map of West Indies.

arc but has also been proved by enormous horizontal-shift faulting between Cuba and Espaniola (Haiti) showing a lateral eastward movement of more than 60 miles. The movement of the Los Bajos fault may be due to a similar, though smaller, eastward movement on the south limb of the arc and should, consequently, have affected not only the normal sediments but also the metamorphic basement itself. An eastward release of stress of this nature again suggests subsidence of the Atlantic.

Effect of Los Bajos Fault on Migration of Oil

Present Position of Accumulation

Oil, in the main oil fields of southern Trinidad, is found generally in lower Miocene beds, known locally as the Forest and Cruse series (*Cyclammina* clays). In the early days, it was thought that oil and gas under gravity separation had accumulated only in the crestal areas of anticlines. It was difficult, however, to explain how, with such intense lateral variation of sands, silts, and clays in these beds, oil could have separated from salt water and could have filled sand lenses only in the crestal zones. With the application of electric logging methods a greatly improved understanding of oil and water distribution has been made possible, and it is found that oil accumulations are not essentially confined to structural "highs," but more especially to regions of disturbance and faulting.

Certain structurally high areas, for example, the north flank of the Fyzabad structure, are comparatively barren, whereas other areas which are structurally low, on the same structural unit, are well impregnated with oil. Good examples of this phenomenon may be seen on the north flank of the Palo Seco structure and the south flank of the Fyzabad anticline.

It is worthy of note that the deepest part of the Siparia syncline, that is, the structurally deepest part of Trinidad between the Los Bajos fault and the Central Range, is well impregnated in the normal zones of accumulation, whereas updip on the same flank a barren area intervenes between this oil accumulation and the Fyzabad field.

The north flank of Palo Seco is associated with the Santa Flora fault. The south flank of Fyzabad is the steeper flank of the structure and is associated with strike-and-dip faulting and, finally, the deepest part of the Siparia syncline is that part in close contact with the Los Bajos fault. These deep accumulations have not extended updip toward the anticlinal crest, owing to the extreme lack of continuity of beds.

It is now apparent that oil accumulation owes its existence in the

Forest and Cruse series to communication with older beds along lines of faulting.

MUD-FLOW

Associated with these accumulations are occurrences of dykes and sills of mud-flow material composed of shiny clay pebbles, sand fragments, and grit in a matrix of sandy and silty clay. This material is similar in many respects to cavings found in wells where flow has been obtained from sands interbedded with incompetent clay.

In the oil-field region, mud-flows have been found to contain mixed forams derived from beds ranging from Cretaceous to Oligocene in age. Many sand fragments and cavities in these mud-flows are well impregnated with oil.[19]

DEEPER SOURCE OF OIL

It is the writer's opinion that these mud-flow phenomena are relics of violent eruptions of material ejected along lines of tension faulting, and it is his belief that these blow-outs were derived, not from slow filtration of oil from a clay source rock or mother rock, but from deep-seated reservoirs where oil and gas have already accumulated and have later been partially released by faulting during a comparatively recent period of disturbance.

From the common occurrence of the various fragments of material found in mud-flows, it is as yet impossible to determine whether the source of the ejections is only Cretaceous (and samples have been gathered from all overlying beds in their upward journey), or whether various zones of accumulation exist also in Eocene and Oligocene beds.

CONCLUSION

The Los Bajos fault phenomenon may be summed up as a horizontal movement eastward (on the assumption that the Guayana shield has remained stationary) of the northern fault block. The fault traverses an area on which approximately 14,000 feet of Tertiary sediments were deposited. That is to say, it gives an almost straight fracture through the Orinoco basin at its thickest as well as its least competent Tertiary development. The writer considers that, in such an area, it is unlikely that the fault was initiated by any previous orogenic movement and that, provided a sufficient southeast gradient was developed, movement took place as a gravitational slumping of incompetent Tertiary beds of the northern block, south-

[19] C. C. Wilson, *Jour. Inst. Petrol. Tech.*, Vol. 16, No. 83 (June, 1930), pp. 578–80; Vol. 19, No. 120 (October, 1933), pp. 878–80.

eastward, past the southern block due to a tilting movement which continued after the late Miocene orogeny. Movement may have taken place only in a superficial Tertiary sheet over a rigid metamorphic basement. An increased competence in Forest-Cruse beds in the Moruga-Guayaguayare area may have obstructed the horizontal movement and caused greater folding and overthrusting, locally, in the northern block compared with that found in the southern block.

Gravitational slumping on a very much smaller scale can be seen in action from time to time in mud-flow deposits on the crestal area of the main southern anticline. There, mud-flow masses have moved toward the sea on very low gradients, and the writer suggests that this type of movement gives a miniature picture of the horizontal-shift faulting phenomena of the highly incompetent beds on the north side of the Los Bajos fault.

On the other hand, if the gradient developed, after the Mio-Pliocene orogeny, was not sufficiently great to induce movement of this nature, then the writer is inclined to the view that this horizontal movement is related to the eastward release of stress shown by folding and horizontal-shift faulting in the Caribbean area generally, as described by Hess. The Los Bajos fault, therefore, is a later equivalent on the south side of the Antillean arc to that of the enormous Bartlett horizontal-shift fault which has moved Espaniola more than 60 miles from its contact with Cuba.

The writer wishes especially to thank H. G. Kugler for his very helpful criticism of this paper and for directing his attention to literature bearing on this subject. He wishes also to thank G. W. Halse, A. G. Hutchison, E. Cooper Scott, and J. A. Bullbrook for their valuable help and the Trinidad Petroleum Development Company, Ltd., for granting permission to publish this paper.

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HOFFMAN FIELD, DUVAL COUNTY, TEXAS[1]

HARVEY WHITAKER[2]
San Antonio, Texas

ABSTRACT

The Hoffman field is located in the Government Wells district of Duval County in southwest Texas. Production is found in five sands in the *Textularia hockleyensis* zone of the Jackson formation, upper Eocene in age. The sands range in depth from 2,500 to 2,900 feet. The field is on a broad anticlinal nose with probably not more than 40 feet of closure on the Jackson. Stratigraphic variations are as important to accumulation as structural relief. Variations in gas-oil and oil-water contacts are pronounced and are probably due to changes in porosity and permeability of the sands although there is some evidence of water coning. No estimate of reserves is practicable except by comparative method. The field is still in the development stage.

LOCATION

The Hoffman field is located in northwest-central Duval County, Texas, on the interior coastal plain. It is accessible by hard-surfaced roads from Benavides and Freer. The field lies 3 miles east and slightly south of the Sarnosa pool, and 3 miles south of the Loma Novia pool (Fig. 1).

HISTORY

Magnetic and torsion-balance work by the Plymouth Oil Company in 1932 disclosed evidence of an anticlinal structure in the vicinity of the field. Their first interpretation located the top of the structure considerably east of its true position. Their Hoffman No. 1, in the center of Section 113 (Fig. 2), had sufficient showings in several sands to warrant further drilling, and a second well was drilled ¾ mile updip, but the showings of oil were little better than were encountered in the first well.

The addition of these wells to the subsurface control in the area indicated a possible closure or at least a strong nose farther updip and this was substantiated by new magnetic work by R. H. Durward of the Plymouth Oil Company.

Conway and Campbell's Hoffman No. 1, discovery well of the field, was located on this information near the north line of Section 114, 1¼ miles due west of Plymouth's Hoffman No. 2, and was completed in August, 1933, producing 20 million cubic feet of dry gas in the Government Wells sand from a depth of 2,751–2,757 feet, with 1,000 pounds pressure. Plymouth's Hoffman No. 3 was drilled two locations east and was 30 feet lower structurally on top of the sand.

[1] Manuscript received, July 17, 1940.

[2] Geologist, Gorman-Yoakam Drilling Company. The writer expresses appreciation to Edgar W. Owen and Charles H. Row for helpful criticism and suggestions, and to the Gorman-Yoakam Drilling Company for permission to publish this paper.

The well was abandoned after a drill-stem test recovered 1,200 feet of salt water, about 10 per cent of which was oil.

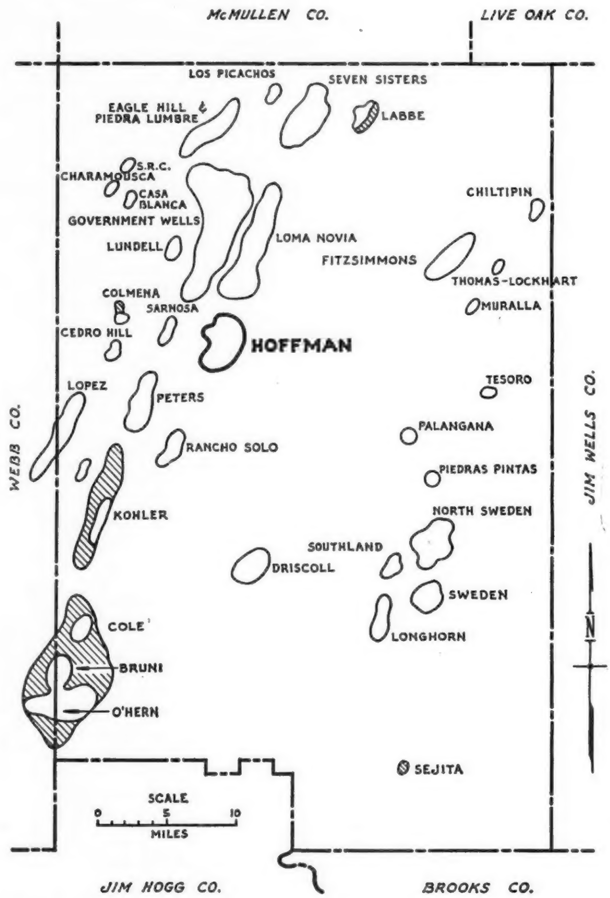


FIG. 1.—Map of Duval County, Texas, showing location of Hoffman field.

The Bridwell Oil Company's Sutherland No. 1 was the second gas well in the field. Its location was $1\frac{1}{4}$ miles north of the discovery (in Section 122) and was completed in March, 1934. Sutherland No. 2, a location north, found the sand 21 feet lower than the gas well. It appeared to be a good oil well when completed but went almost immedi-

ately to water. Sutherland No. 1-A, two locations west of No. 2, established the first oil production from the Government Wells sand, found from 2,707 to 2,713 feet, in July, 1935. The initial production was 100 barrels per day, flowing, but water soon broke in and could not be shut off.

The thin oil column disclosed by this drilling discouraged development and for a year and a half there was little activity. In January, 1936, Rogers' Sutherland No. 1 was drilled in the southeast corner of Survey 120. It was completed in the lower Loma Novia sand from 2,870 to 2,875 feet producing 484 barrels per day. This led to immediate development of the field and orderly drilling has continued to the present.

Bridwell-Gorman-Yoakam's Robles No. 1, in the southwest corner of Survey 68, discovered upper Loma Novia sand production at a depth of 2,810–2,825 feet in October, 1936. The initial production was 75 barrels per day, pumping.

Cox and Hamon-Gorman-Yoakam's Cuellar No. 1, in the center of Survey No. 117 (west), provided a half-mile south extension to the field in the Government Wells sand in October, 1937. Their Cuellar No. 3 discovered the Argo sand production through perforations from 2,550 to 2,570 feet. The well was completed, November 25, 1937, producing 20 barrels an hour.

TOPOGRAPHY

The Hoffman field is located on the Oakville belt of hills and the topography is typical of this belt of country, being a succession of high ridges and broad valleys. The ridges are covered with caliche and numerous outcrops of Oakville sandstone. The soil is very poor buff sandy loam and red or buff clay, and due to this and the semi-arid condition of the region, only a small amount of cultivation is attempted in the valleys where the soil is good. The principal vegetation is cactus, mesquite, and chaparral. The elevation varies from 743 to 615 feet with the highest elevation coinciding with the top of the structure.

STRATIGRAPHY

SURFACE

The youngest beds found in the Hoffman area are Oakville, lower Miocene in age. These beds consist mainly of sand (commonly quartzitic) with some sandstone conglomerates and buff clays. The sands are buff to brown in color with dark iron-stain banding.

At several localities in and near the field the Catahoula (Oligocene), underlying the Oakville, is exposed. The uppermost member, in con-

TABLE I

GEOLOGIC SECTION, HOFFMAN FIELD

Series	*Group*	*Formation*		*Lithologic Description*	*Thickness in Feet*	*Remarks*
Miocene		Oakville		Buff clay with massive sand at base	0–100	
Oligocene	Upper	Catahoula (Geuydan)	LaChusa	Predominantly volcanic ash with thin volcanic sands	?	
			Soledad	Heavy conglomeratic sand and gravel	100?	Good source of drilling water in most of field
			Fant	Massive white ash and thin ashy sands	?	
	Lower	Frio		Predominantly red and green clay; in places purple. Thin, green, fine-grained argillaceous sands. Thin lignites at base	?	Sands very lenticular
Eocene	Jackson	Whitsett		Green to black, bentonitic shale. Rhyolitic, "salt-and-pepper" sands. Shell fragments and thin to heavy lignites	250	First *Discorbis jacksonensis*
		McElroy		Same as above. Red section present in some places near top. Heavy black lignite on top of basal Mirando sand	950	First *Textularia hockleyensis*. Oil-bearing sand zones
		Caddell		Green and black clay. Prominent glauconite	70	First *Textularia dibollensis*
	Claiborne	Cockfield		Gray micaceous, glauconitic sands. Brown, lignitic and dark green and black shales	300	First *Nonionella cockfieldensis*
		Yegua		Same as above	?	First *Eponides yeguaensis*

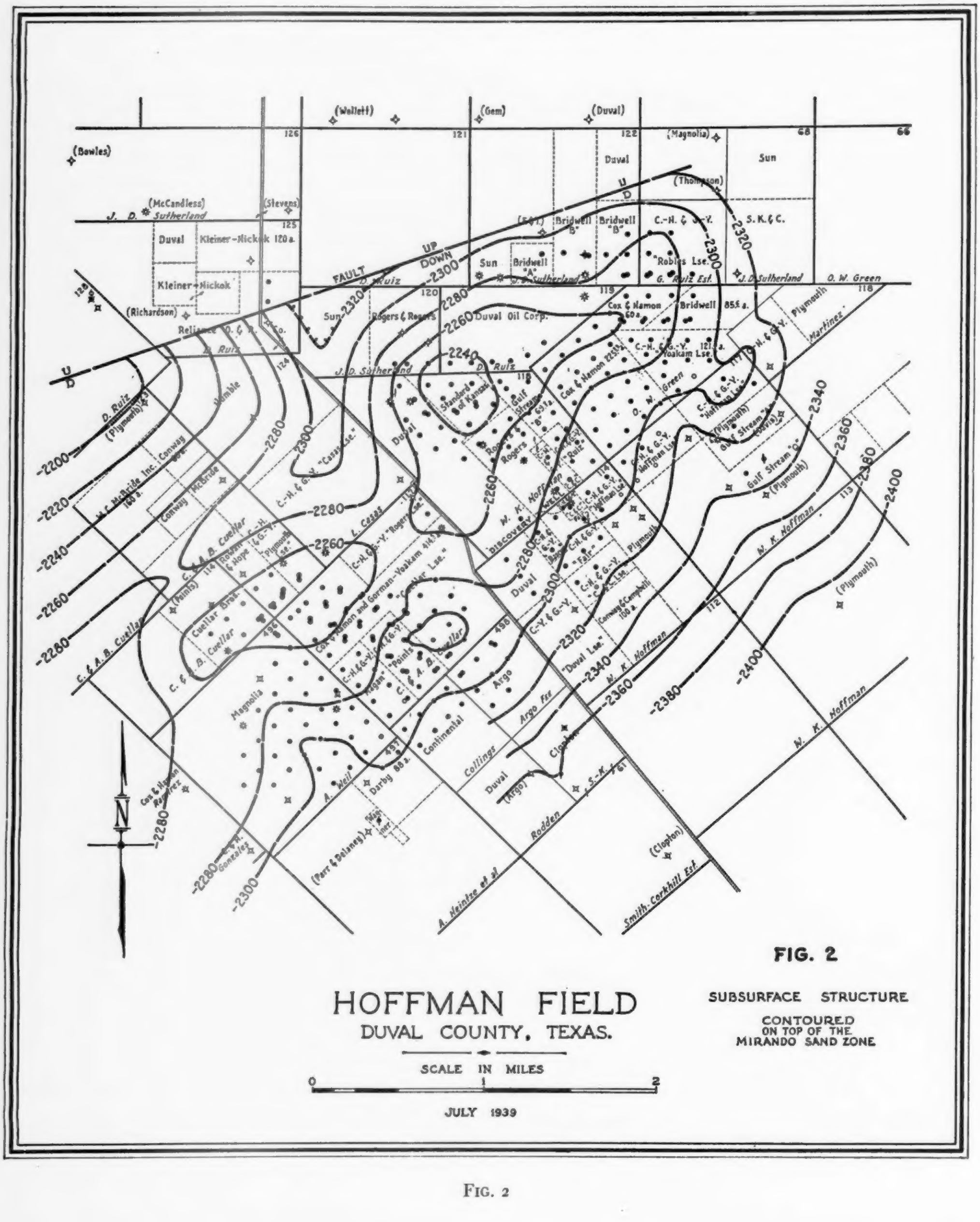


FIG. 2
HOFFMAN FIELD
DUVAL COUNTY, TEXAS.
SUBSURFACE STRUCTURE
CONTOURED ON TOP OF THE MIRANDO SAND ZONE
SCALE IN MILES
JULY 1939

FIG. 2

tact with the Oakville, is gray to white volcanic ash. This is the La Chusa of Bailey's[3] Gueydan formation.

SUBSURFACE

The formations from the surface to the top of the Jackson have not been carefully differentiated in this area due to the inability to determine the contacts from the lithologically non-marine character of the sediments. The Jackson (Eocene) bears a good marine fauna and the diagnostic Foraminifera of its various members are readily found.

Table I gives a brief description and the approximate thicknesses of these formations.

The sands of the Jackson can not be differentiated by lithology, and due to their lenticular nature, a complete log is necessary to identify the various sands except in areas with close control. The sands are generally shaly and the shale content of the producing sands increases updip until they become sandy shale, then shale (Fig. 7).

STRUCTURE

SURFACE

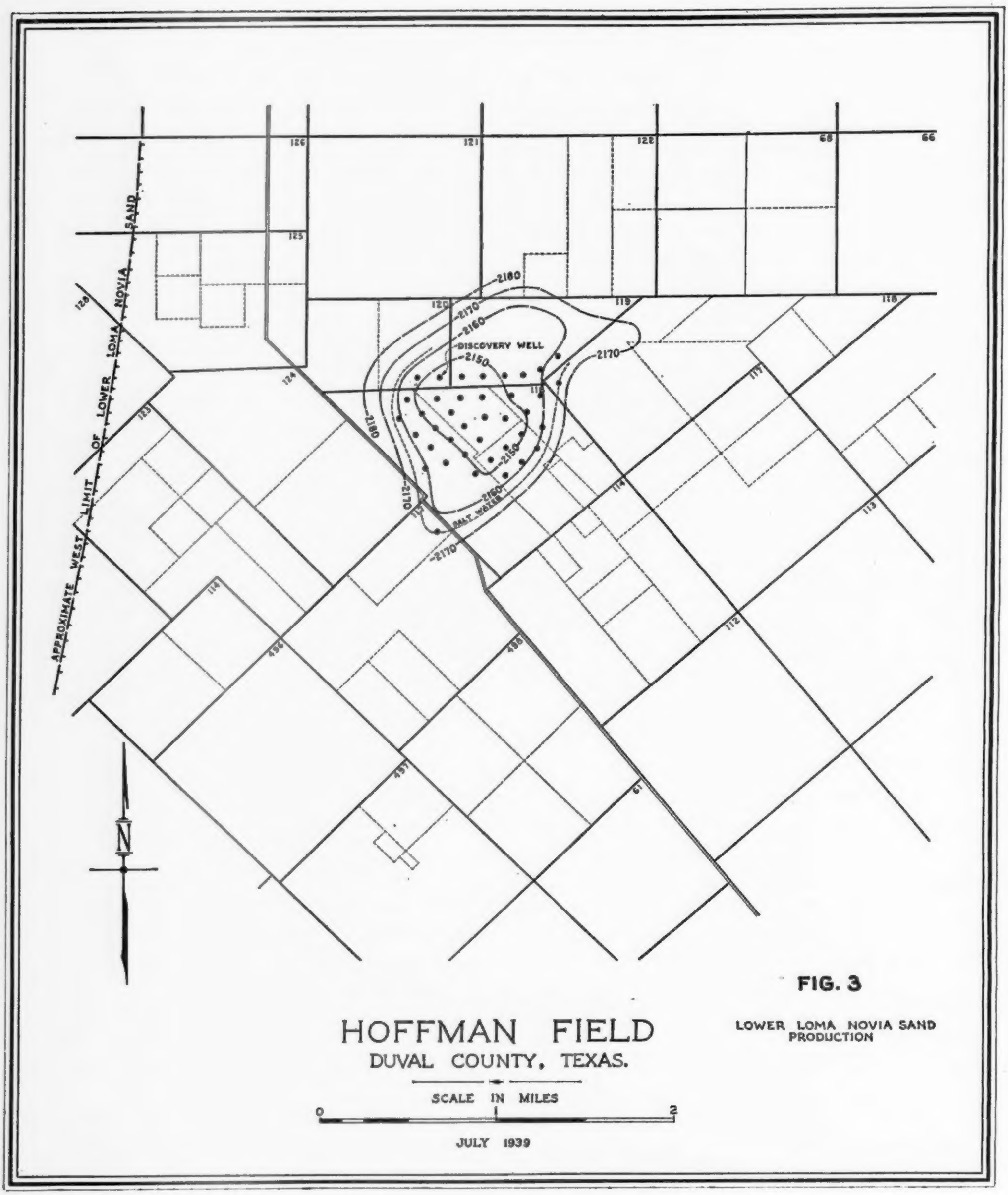
The discontinuous outcrop of the Oakville and the Oakville-Catahoula contact allow very poor control in the vicinity of the Hoffman field, but such work as can be done shows only a broad nose. The fault on the north end of the field has not been found on the surface. The topography of the area suggests the structure but this is probably coincidental.

SUBSURFACE

The subsurface structure as mapped on top of the Mirando sand zone shows a long, low anticline with a fault cutting across its north end. A saddle in the middle of the feature produces two separate closures with the northern closure being the higher. There are insufficient data to show the exact amount of closure and only 30 feet can be proved, with a possibility that there is more. The fault at the north end of the field is a normal dip-fault downthrown toward the south. Its strike is approximately N. 70° E. At the one point of close control between Reliance's Ruiz No. 2 and No. 3, in Section 125 west of the field, the throw is 160 feet. This apparently decreases to the northeast.

Due to their uneven surfaces the sands make poor datum planes. For this reason the map (Fig. 2) is drawn with contours on top of the Mirando zone which is an estimated value except in a few deeper wells. False dips due to lenticularity have thus been eliminated.

[3] Thomas L. Bailey, "The Gueydan, a New Middle Tertiary Formation from the Southwestern Coastal Plain of Texas," *Univ. Texas Bull. 2645* (December 1, 1926).



APPROXIMATE WEST LIMIT OF LOWER LOMA NOVIA SAND
DISCOVERY WELL
SALT WATER
-2150
-2160
-2170
-2180
126
121
122
68
66
125
120
119
118
128
124
123
117
116
115
114
113
112
496
498
497
61
N
FIG. 3
LOWER LOMA NOVIA SAND PRODUCTION
HOFFMAN FIELD
DUVAL COUNTY, TEXAS.
SCALE IN MILES
0
1
2
JULY 1939

FIG. 3

The Soledad sandstone (Catahoula) found from 500 to 700 feet, is a very persistent bed over most of the area but grades into shale in the northeastern part of the field. Using the base of this sand as a datum plane the structure is mapped with considerably more relief than can be shown on any of the producing sands. This indicates that the sand was deposited over a topographic feature which expressed an exaggeration of the structure at that time.

An anomaly on the base of this sand on the west side of Rowan and Hope's Cuellar lease in Section 114 indicates some minor faulting, downthrown toward the south. There is not enough information as yet to show this feature.

PRODUCING FORMATIONS

LOWER LOMA NOVIA SAND

The lower Loma Novia sand is the deepest producing formation in the field at present and is found from 2,840 to 2,900 feet. The production is confined to the top of the structure since the sand extends several miles west beyond production. This is the only sand producing from purely structural accumulation. There is an average of not more than 10 feet of sand above water and it contains no free gas. The sand is medium fine-grained and generally shaly but porous and highly permeable. The sand has little pressure and most of the wells did not flow. Nearly all have a high fluid level and the oil is produced efficiently by jetting. Recently most operators have installed pumping equipment.

This sand has an efficient water drive, which is responsible for a rather good recovery from a small amount of sand. Most of the wells make water but there is little appreciable increase in water production. To August 1, this oil production was approximately 2,300 barrels per acre.

The total area of the lower Loma Novia production is 420 acres. There are 39 producing oil wells. This production may be extended slightly but its limits are well defined.

UPPER LOMA NOVIA SAND

The production from the upper Loma Novia sand has been very disappointing in the north part of the field. The sand is present only on the downdip side of the structure and is poorly developed. It covers most of the south part of the structure where it is cleaner but thin. On top of the structure it has shaled out entirely or is represented by 4 or 5 feet of very shaly sand showing oil. Bridwell and Gorman-Yoakam's Robles No. 1 was drilled in the southwest corner of Section

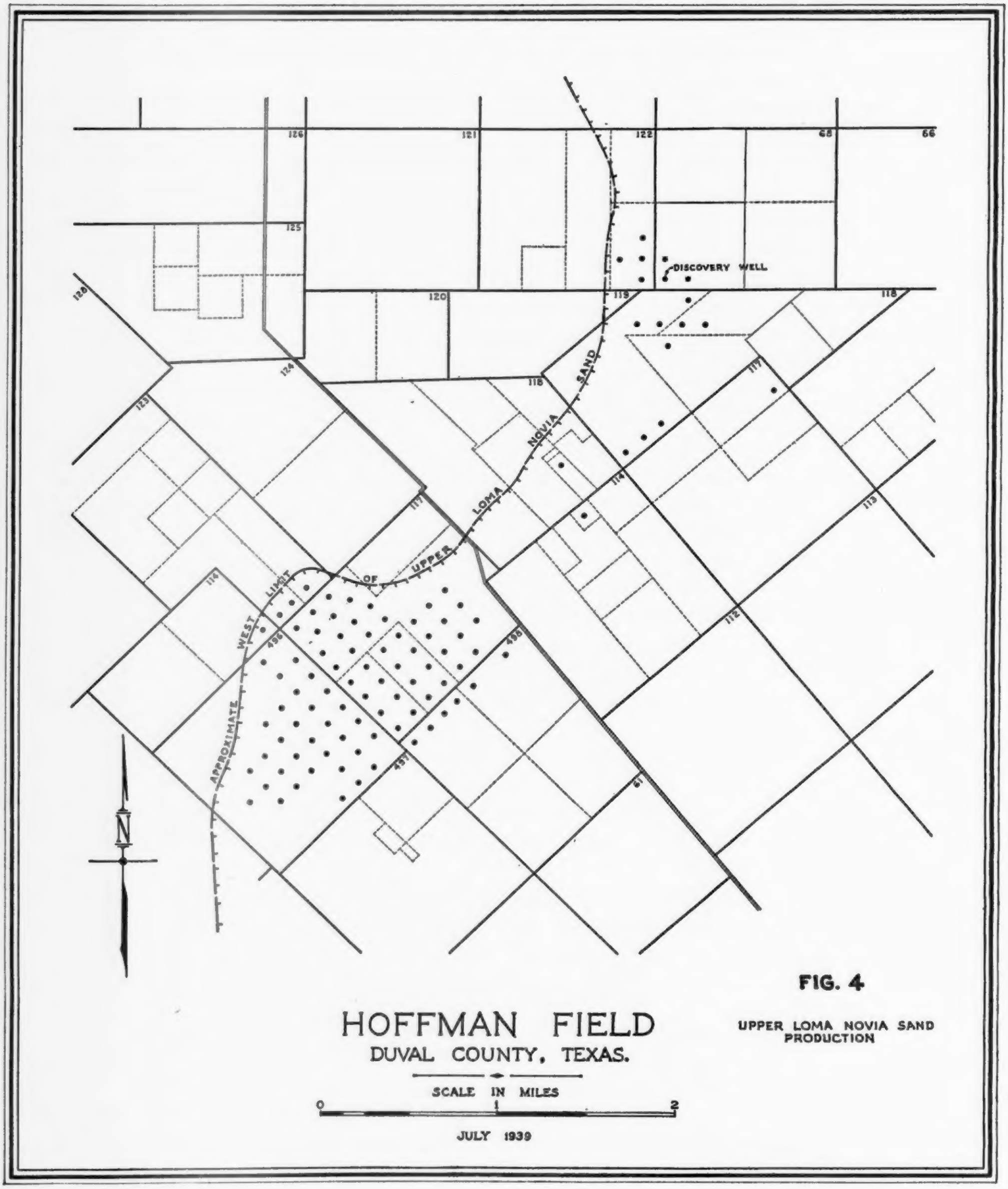

126
121
122
68
66
125
128
120
119
118
DISCOVERY WELL
124
118
123
117
111
114
113
112
116
496
495
497
61
APPROXIMATE WEST LIMIT OF UPPER LOMA NOVIA SAND
N
FIG. 4
UPPER LOMA NOVIA SAND PRODUCTION
HOFFMAN FIELD
DUVAL COUNTY, TEXAS.
SCALE IN MILES
0
1
2
JULY 1939

FIG. 4

68 on the theory that the showings on top were from the wedge end of the sand and better development would be found on the east flank of the structure. The sand was found at 2,810–2,825 feet but was shaly. The well produced 75 barrels per day on the pump with no pressure.

Eighteen other wells were drilled in this vicinity and in all the sand was tight and shaly. Production ranged from 25 to 75 barrels on jet or pump.

At the south end of the field (Sections 496 and 497) the sand is generally much cleaner although it is typically shaly in spots. There is an average of not more than 10 feet of effective sand. The best wells flow a maximum of 20 barrels an hour initially. The upper Loma Novia sand in this area is found at depths ranging from 2,775 to 2,850 feet. The accumulation is caused by the sand shaling updip. There is no free gas in the sand but the wells have good flowing pressures where the sand is clean. There is apparently a good water drive in this sand in the south end of the field.

There are 102 wells in the upper Loma Novia sand. There is a large undeveloped area within the limits of production but most of such locations are of dubious value. The wells producing from the Government Wells zone will be deepened to test this sand when they are depleted.

GOVERNMENT WELLS SAND

Production from the Government Wells sand covers the entire field (Fig. 5). The sand is found at depths ranging from 2,650 to 2,750 feet. It is primarily a gas sand, but there is an oil column that averages 7 or 8 feet in thickness throughout the field (varying from 4 feet to 18 feet) where the condition of the sand will allow accumulation. The sand thins from a thickness of 100 feet on the east edge of the field to 35 feet just west of the field. The lower part of the sand contains water over the structure.

The oil accumulation seems to be governed mainly by the porosity and permeability of the sand. On top of the structure where the sand is shaly and tight, the gas-oil contact is generally found between a subsea datum of 2,040 and 2,045 feet. On the east flank, where the sand is very porous and permeable, it is as high as minus 2,018 feet. Apparently, the gas cap has depressed this contact.

The water level is approximately minus 2,050 feet, but a number of wells have produced water from depths 15 feet above this datum, and a few wells produce no water at a minus 2,060 feet. The reason for this apparently uneven water level is unknown to the writer. It is

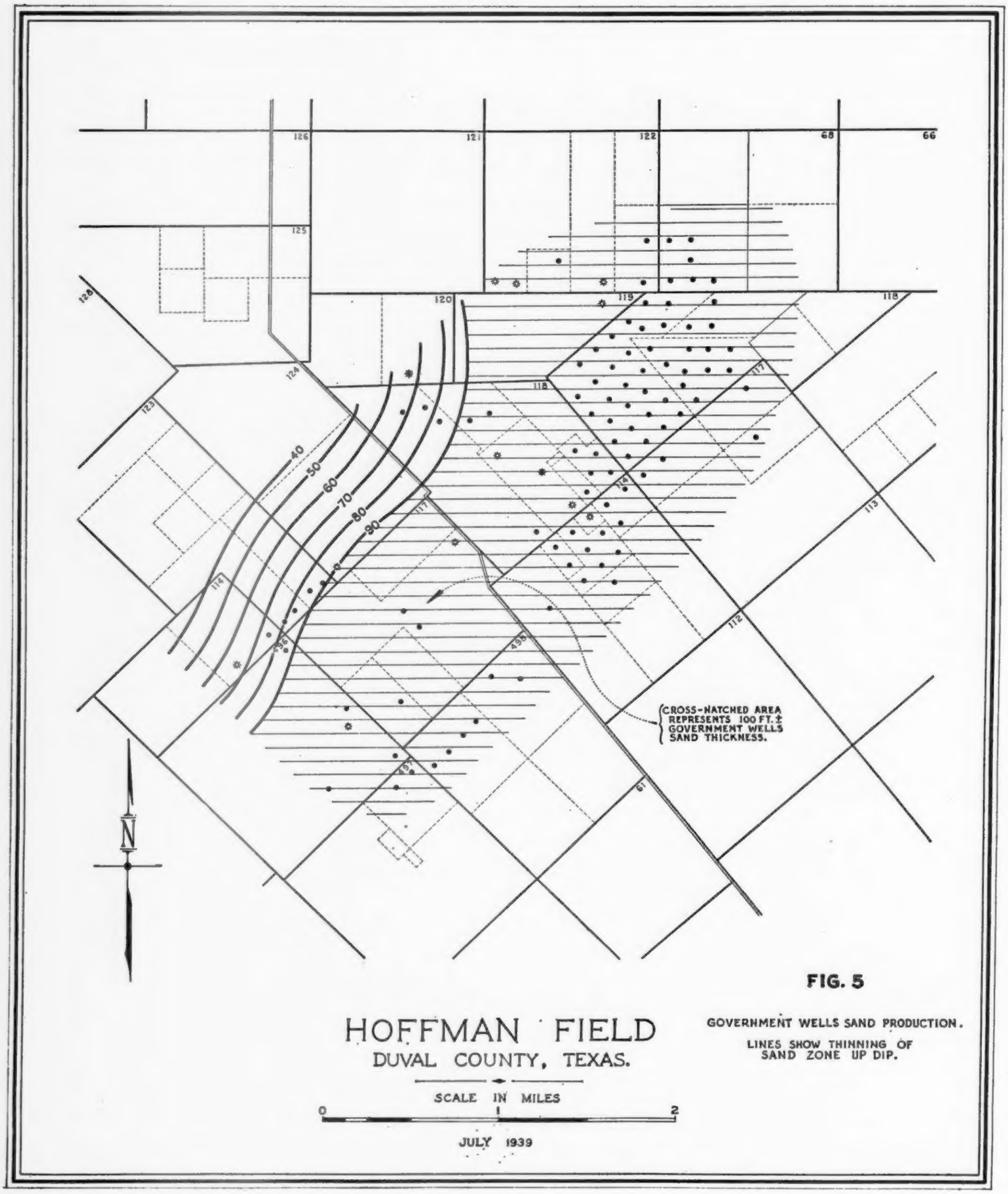

HOFFMAN FIELD
DUVAL COUNTY, TEXAS.
SCALE IN MILES
0
1
2
JULY 1939
FIG. 5
GOVERNMENT WELLS SAND PRODUCTION.
LINES SHOW THINNING OF SAND ZONE UP DIP.
CROSS-HATCHED AREA REPRESENTS 100 FT.± GOVERNMENT WELLS SAND THICKNESS.
N
40
50
60
70
80
90

Fig. 5

partly explained by the fact that the water, underlying the oil in the entire field, moves more readily through the sand than the oil. This coning action has been observed and recognized in several wells.

Another plausible explanation is the theory that the structure is too young to allow a complete separation of the fluids. The Government Wells sand has more closure than any other sand (30 feet structural, plus 35 feet stratigraphic) yet the fluid separation in it is poorer than in any other sand. Supporting this theory is evidence that much of the movement took place later than Soledad time. A combination of structural and stratigraphic closure is responsible for this accumulation.

The Government Wells sand has a highly efficient water drive and, due to this, it is expected that a large percentage of its oil will be recovered.

The original gas pressure of 1,000 pounds has been nearly dissipated except in the south part of the field and, as a consequence, most of the wells are being pumped.

Since the oil column is comparatively thin, a shale break or tight place in the sand, where the saturation should be, will result in a gas well or a dry hole. For this reason, the Government Wells producing area has not been completely developed.

There are 97 oil wells and 12 gas wells completed in this sand.

ARGO SAND

The Argo sand derived its name from a small producer in the east quarter of Section 498, about ½ mile southeast of the field, drilled by the Argo Oil Company. This well was the only producer in an apparently isolated lens. Production fell off rapidly after completion and the well was soon abandoned.

This sand lies about 100 feet above the Government Wells sand and is finer-grained than any other producing sand. In most wells it is clean sand. It varies from 5 to 40 feet in thickness and is confined to a narrow tongue-shaped lens greatly resembling a stream bed.

There is no water in this sand and no free gas, but a sufficient amount to flow most of the wells. The wells vary widely in producing capacity, being entirely controlled by the character of the sand rather than position on the structure.

The Argo sand presents an exceptional distribution pattern for this section. It greatly resembles a stream bed but there is no evidence supporting the conclusion that this was its origin. As it produces downdip beyond the limits of production in other sands it can not be proved that it is an isolated lens, but there is no prominent body of

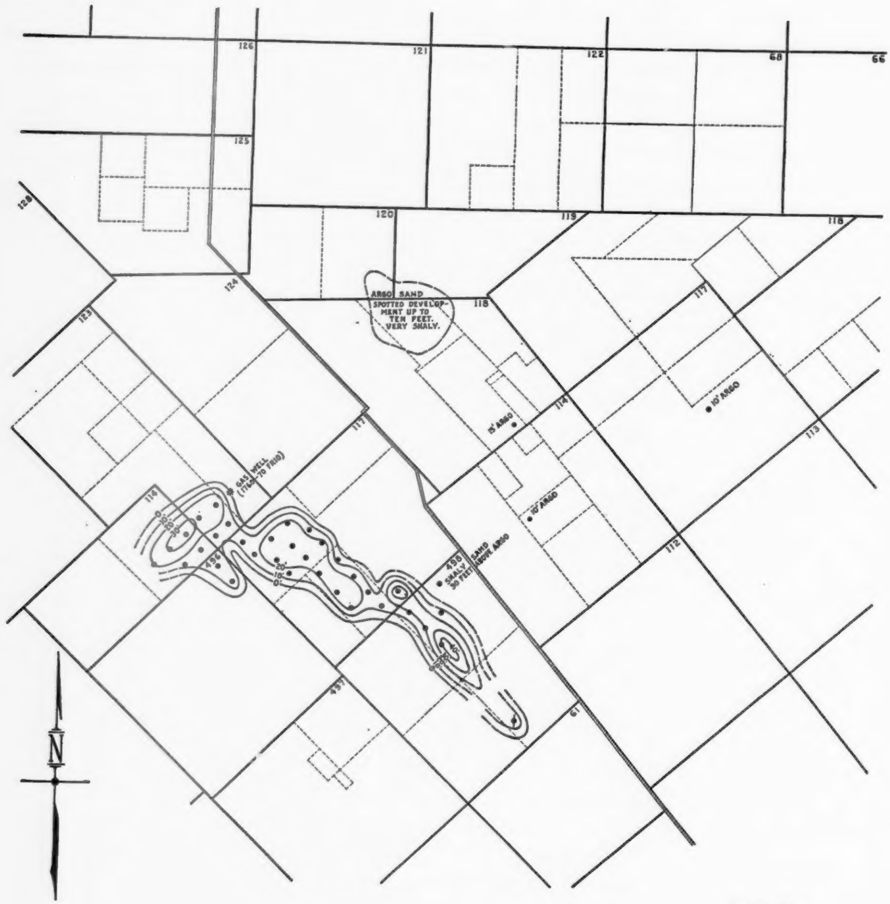


FIG. 6

ARGO SAND PRODUCTION
ISOPACH OF SAND INTERVAL

HOFFMAN FIELD
DUVAL COUNTY, TEXAS.

SCALE IN MILES

0 1 2

JULY 1939

Fig. 6

it developed anywhere. Since its shape provides for closure on normal dip, it is considered a fortunate coincidence that it was found on the structure rather than being related to it.

There are isolated patches of this sand, as shown in Figure 6. It is probably an off-shore bar but more work must be done before an explanation for its occurrence can be definitely stated.

The producing area is definitely delineated in the field itself but extensions are probable on either end of the lens.

There are 37 oil wells in the Argo sand.

FRIO PRODUCTION

A gas well was completed accidentally in Cox and Hamon, Gorman-Yoakam's Plymouth (Cuellar) No. 3 in Section 123 in the southwest part of the field. The pipe was shot off in this well at 1,780 feet and a large flow of gas with 500 pounds pressure resulted. It is apparently producing from a sand found on the electrical log at 1,760–1,780 feet. This appears to be a more or less blanket sand throughout the field, but has not been cored or tested in any well.

DEVELOPMENT

DRILLING

With the exception of a thin quartzitic sand here and there, the drilling in the Hoffman area is easy. Fish-tail bits are used from top to bottom. A 12-inch hole is carried to 20 feet where $10\frac{3}{4}$-inch surface pipe is set. A $9\frac{7}{8}$-inch hole is drilled to the producing sand and 7-inch outside dimension or $5\frac{1}{2}$-inch outside dimension pipe is set.

Light power or steam rigs are used, as plenty of water is available from the Soledad formation at about 500 feet. No commercial muds are required as the formations make good mud from the surface, although some returns are lost in the Soledad and at 1,200–1,500 feet. This difficulty is not serious.

It requires about 4 days from spudding to setting the oil string unless there is an excessive amount of coring and testing.

In the lower Loma Novia production, the Argo (if present), Government Wells, and the thin upper Loma Novia saturations are cored and commonly tested before pipe is set. The producing possibilities of these sands are carefully noted, as the operators intend to perforate these sands or twin their locations when the lower sand is depleted.

On the northeast flank of the structure, the original plan was to complete in the upper Loma Novia sand and later perforate the Government Wells. However, after a few disappointing attempts to complete in the Government Wells by this method, it was abandoned as

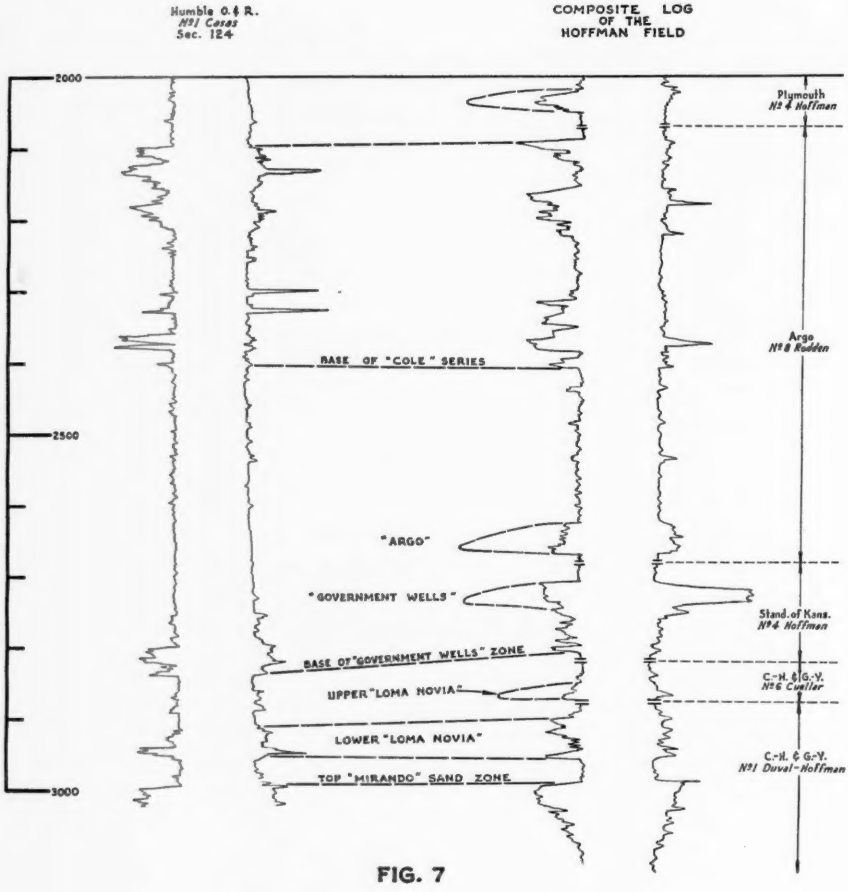

Humble O. & R.
Nº1 Casas
Sec. 124
COMPOSITE LOG OF THE HOFFMAN FIELD
2000
2500
3000
BASE OF "COLE" SERIES
"ARGO"
"GOVERNMENT WELLS"
BASE OF "GOVERNMENT WELLS" ZONE
UPPER "LOMA NOVIA"
LOWER "LOMA NOVIA"
TOP "MIRANDO" SAND ZONE
Plymouth
Nº 4 Hoffman
Argo
Nº 8 Rodden
Stand. of Kans.
Nº4 Hoffman
C.-H. & G.-Y.
Nº6 Cuellar
C.-H. & G.-Y.
Nº1 Duval-Hoffman
FIG. 7
CORRELATION OF HOFFMAN WITH UP-DIP SECTION

FIG. 7

impractical. It appeared to be impossible to complete such a well by this method which would not produce an excessive amount of water. The most successful method of completion in the Government Wells has been to penetrate the sand as little as possible, it having been discovered that 2 feet of good saturation would yield as well as a thicker section. The mud is then swabbed or jetted off the sand slowly enough to be replaced with oil so that a good column of fluid is always exerting a pressure on the sand.

Since all the producing sands are medium fine-grained and unconsolidated, there is considerable sand trouble in the field if the wells make any appreciable amount of water. As fine-gauged wire-wrapped screen did not solve this problem, the common perforated liners are generally used.

Most of the wells in the northern, or old, part of the field have gone on the pump. Central powers are used on all leases except the Duval Oil Corporation properties where individual electric-powered units have been installed. Due to the wide variation in the production of the wells, these units have the advantage of independent operation over the central power.

PRODUCTION

The Hoffman field has been produced under proration as shown in Table II.

TABLE II

DAILY ALLOWABLE PRODUCTION

	1937	*1938*	*1939*
January	23	21.50	16.32
February	23	19.71	15.71
March	23	20.00	16.32
April	23	19.93	16.67
May	23	16.32	17.29
June	23	16.13	16.13
July	23	18.45	16.32
August	23	19.16	
September	23	16.13	
October	23	16.32	
November	23	16.13	
December	23	16.32	

To August 1, 1939, the total production from the field was 2,896,-334 barrels.

OUTLETS

The Humble Pipe Line Company began buying oil in August, 1935. Its 6-inch line passes through the north end of the field and delivers the oil at tidewater at Ingleside, Texas. The Crude Oil Purchasing Company provides the other outlet for the field. Its 4-inch line passes through the south part of the producing area, and delivers the oil to Corpus Christi, Texas.

DEEPER POSSIBILITIES

The deepest test in the Hoffman field is Rogers' Hoffman No. 2 in Section 118, which was drilled to a depth of 3,605 feet. This test was plugged back and completed in the Government Wells sand as a gas well. At its total depth the well was 350 feet in the Yegua formation, and no showings of importance were encountered below the lower Loma Novia horizon.

TABLE III

SUMMARY OF DATA

Producing Sand	*Number of Wells*	*Aver. Total Depth in Feet*	*Water Level in Feet*	*Gravity (Degrees)*	*Discovery Date*
Argo	37 oil	2,595	?	26–28	Nov., 1937
Government Wells	12 gas 97 oil	2,740	−2,050	20–21	Aug., 1933
Upper Loma Novia	102 oil	2,845	−2,180	23–25	Oct., 1936
Lower Loma Novia	39 oil	2,875	−2,165	23	Jan., 1936

Total number of wells	275 oil, 12 gas
Total estimated productive area	2,400 acres
Total production (August 1, 1939)	2,896,334 barrels
Average drilling (spud to completion) time	7 days
Average cost, completed well	$9,500.00

The Yegua formation is estimated to be 1,000 feet thick in this locality (from near-by tests) and the whole formation is very sandy. These sands are lenticular and it is possible production may be found somewhere in the section.

The Cook Mountain formation is predominantly shale. The Queen City and Wilcox sands, in the lower part of the Eocene, offer the best deeper possibilities. There have been no wells drilled to reach these sands in this area, so there is little information to aid in approximating their depths. A rough estimate places them at 6,500 and 10,000 feet, respectively.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 12 (DECEMBER, 1940), PP. 2143-2149, 1 FIG.

STRUCTURAL INTERPRETATION OF RECENT GRAVITY OBSERVATIONS IN SOUTHEASTERN OKLAHOMA[1]

THOMAS A. HENDRICKS[2]
Washington, D. C.

ABSTRACT

Fourteen new gravity determinations have been made by the United States Coast and Geodetic Survey on and near the north border of the Coastal Plain in southeastern Oklahoma. The stations are located near township corners and form a grid surrounding the junction of the Ouachita and Arbuckle mountain systems beneath Cretaceous strata of the Coastal Plain. Gravity anomalies computed by the Coast and Geodetic Survey show a broad nose of high positive anomalies that coincides with the granite core of the Tishomingo anticline of the Arbuckle Mountains and with its southeastward prolongation beneath the Coastal Plain. The nose extends southeastward in such a way as to form a large southeastward reëntrant at least 12 miles deep in the northwest front of the Ouachita Mountain structural province between Atoka, Oklahoma, and Denison, Texas.

Early in 1938 several geologists of the United States Geological Survey selected areas with which they were familiar in which they thought that gravity determinations might yield significant geologic data. The areas were selected at the request of the United States Coast and Geodetic Survey and outlines of proposed projects for gravity determinations were submitted to that Survey for consideration. The purpose of this paper is to present the results obtained in one of those projects together with an interpretation of the geologic significance of the results.

In November and December, 1938, a field party working under the direction of R. W. Woodworth occupied and made pendulum gravity observations at 14 new stations in Atoka and Bryan counties, Oklahoma, and in addition reoccupied an old station at Wapanucka in Johnston County. It is interesting to note that observations were made at the 15 stations in a total elapsed time of 29 days and that twice in the course of the field work observations were completed at different stations each day for four consecutive days. Computations of the results made by the Coast and Geodetic Survey are given in Table I.

Most of the stations lie on Cretaceous strata of the Gulf Coastal plain (Fig. 1). They form a grid on approximately 6-mile centers surrounding the intersection of the projection of two pronounced lines of pre-Cretaceous deformation beneath gently dipping Cretaceous strata. One of these is the Choctaw fault, a large overthrust from the

[1] Manuscript received, July 27, 1940.

[2] United States Geological Survey.

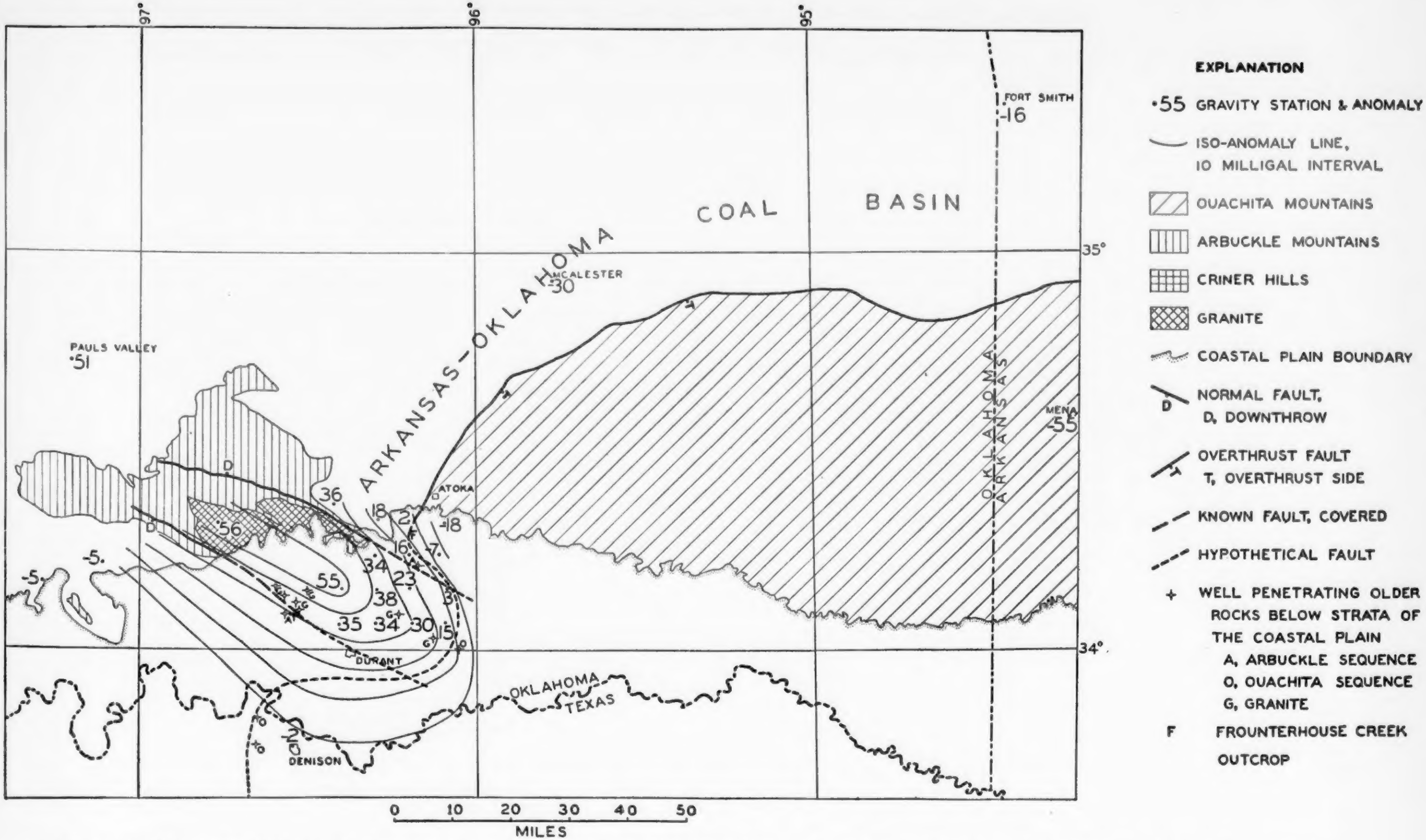


FIG. 1.—Map showing relationship between gravity anomalies and major structural features in southeastern Oklahoma and parts of adjoining states. Cretaceous strata of Coastal Plain form thin cover above Paleozoic and pre-Cambrian rocks similar to those exposed in Arbuckles, Ouachitas, and other regions.

TABLE I

PRINCIPAL FACTS FOR GRAVITY STATIONS*

Station Number	Latitude	Longitude	Elevation Meters	Observed Gravity	Theoretical Gravity	Correction to Theoretical Gravity for: Elevation	Topography to Zone o	Indirect Effect	Topog. and Compensation —96 Km.	Anomaly: Free-Air	Bouguer	Pratt-Hayford 96 Km.
	ϕ	λ		g	γ_0					$g-\gamma$	$g-\gamma''$	$g-\gamma_0$
977	34°14.7′	96°12.0′	154.2	979.645	979.6819	−.0476	+.0175	−.0028	−.0051	+.011	−.007	+.016
978	34°19.8′	96°11.8′	193.2	979.630	979.6890	−.0596	+.0219	−.0028	−.0012	+.001	−.021	+.002
979	34°14.7′	96°06.6′	189.3	979.616	979.6819	−.0584	+.0215	−.0028	−.0006	−.008	−.029	−.007
980	34°19.5′	96°05.5′	191.7	979.610	979.6886	−.0591	+.0217	−.0028	−.0010	−.020	−.041	−.018
981	34°20.1′	96°17.4′	163.4	979.652	979.6894	−.0504	+.0186	−.0028	−.0053	+.013	−.006	+.018
982	34°14.6′	96°18.2′	211.8	979.651	979.6817	−.0654	+.0240	−.0028	+.0007	+.035	+.011	+.034
983	34°09.4′	96°11.9′	197.8	979.637	979.6746	−.0610	+.0224	−.0028	+.0001	+.023	+.001	+.023
984	34°09.5′	96°05.2′	188.4	979.619	979.6747	−.0581	+.0211	−.0028	−.0006	+.002	−.019	+.003
985	34°04.2′	96°05.6′	218.2	979.618	979.6673	−.0673	+.0247	−.0028	+.0033	+.018	−.007	+.015
986	34°04.2′	96°11.5′	189.3	979.639	979.6673	−.0584	+.0215	−.0028	+.0003	+.030	+.009	+.030
987	34°04.3′	96°18.1′	193.2	979.641	979.6674	−.0596	+.0219	−.0028	−.0006	+.033	+.011	+.034
988	34°09.4′	96°17.8′	200.9	979.651	979.6746	−.0620	+.0228	−.0028	−.0001	+.038	+.016	+.038
989	34°04.2′	96°24.6′	197.8	979.641	979.6673	−.0610	+.0224	−.0028	−.0005	+.035	+.012	+.035
990	34°09.5′	96°24.1′	198.1	979.668	979.6747	−.0611	+.0224	−.0028	−.0009	+.054	+.032	+.055

* Taken from "Principal Facts for Gravity Stations in the United States," Part 5, pp. 926–1081, Department of Commerce, U. S. Coast and Geodetic Survey (1940).

southeast that trends northeastward and forms the northwest front of the Ouachita Mountains. The other is a large fault that trends southeastward almost normal to the Choctaw fault and lies on the northeast flank of the Tishomingo anticline. The fault has been interpreted by Joseph A. Taff[3] as a high-angle normal fault and by Robert H. Dott[4] as a high-angle reverse fault. In its surface expression it separates pre-Cambrian granite on the crest of the Tishomingo anticline from Cambrian to Mississippian strata of the facies characteristic of the Arbuckle Mountains on the northeast side of the fold and fault. The stratigraphic displacement on the fault is of the order of magnitude of 5,000 feet.

These two faults divide southeastern Oklahoma into three segments, each of which is underlain by rocks markedly different from those in the other segments. Southeast of the Choctaw fault lies a thin sequence of pre-Pennsylvanian strata overlain by a series of more than 20,000 feet of clastic Pennsylvanian sediments of the facies characteristic of the Ouachita Mountains. These strata are broken by numerous thrust faults. North of the two faults in the area of the gravity observations lie about a thousand feet of clastic Pennsylvanian sediments of the Arkansas-Oklahoma coal basin underlain by about 10,000 feet of Cambrian to Mississippian strata consisting principally of limestones and dolomites belonging to the facies characteristic of the Arbuckle Mountains. The most southwesterly segment consists of the pre-Cambrian Tishomingo granite which contains at the southeast end of the Arbuckle Mountains, one down-faulted inlier of Cambrian and Ordovician limestone, and Cambrian sandstone of the facies characteristic of the Arbuckle Mountains.

When the project was suggested it was hoped that the gravity anomalies would be markedly different on the three segments and that it would be possible to show that one of the previously mentioned faults terminated against the other at the intersection of their projections beneath the strata of the Coastal Plain. As was expected, the highest positive anomalies were found on the granite and its southeastward extension beneath the Coastal Plain; smaller positive anomalies were found on the segment where limestone and dolomite are predominant; and negative anomalies were found on the segment underlain by thick Pennsylvanian clastic sediments. However, no sharp termination of any two of those lithologic groups against the third can be inferred from the anomalies.

[3] J. A. Taff, "Atoka, Indian Territory (Oklahoma)," *U. S. Geol. Survey Atlas Folio 79* (1902), structure sections.

[4] R. H. Dott, "Overthrusting in Arbuckle Mountains, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 5 (May, 1934), p. 587.

The gravity anomalies were plotted on the State geologic map of Oklahoma, and iso-anomaly lines were drawn mechanically without any attempt to adjust them to fit the geologic structure. The prominent feature revealed by those lines is a large southeastward extension of the area of high positive anomalies on the granite of the Tishomingo anticline. Presumably, the southeastward extension of high positive anomalies coincides with a southeastward-plunging projection of granite beneath the Cretaceous sediments of the Coastal Plain. This conclusion is in part substantiated by data supplied by four wells between Atoka and Durant that passed through the Cretaceous strata into older rocks (Fig. 1).

Three of these wells are on a southeastward-trending line about 10 miles northeast of Durant. According to B. H. Harlton[5] granite was encountered in the most northwesterly of the three wells at a depth of about 1,250 feet and in the middle well at about 550 feet. Harlton[6] has also informed the writer that the most southeasterly well encountered no granite but passed from Cretaceous strata into sediments of the facies characteristic of the Ouachita Mountains at a depth of approximately 1,500 feet.

It is apparent, therefore, that the Choctaw fault either terminates against the northeast side of the granite mass or swings southeastward north of and more or less parallel with the northeast side of the granite area. If the Choctaw fault terminates against the granite without bending southeastward the three segments of rocks of different lithologic types should be clearly outlined. The limestone sequence should be confined to the segment north of the junction of the two faults, the thick sequence of clastic Pennsylvanian strata should lie in the segment east of the junction of the faults, and granite should be in contact with each of those sequences at the fault that tends southeastward.

A small exposure of strata of a facies characteristic of the Ouachita Mountains is present in Frounterhouse Creek, Sec. 19, T. 3 S., R. 11 E., about 6 miles southwest of the point where the Choctaw fault passes beneath the Coastal Plain (Fig. 1). That exposure permits the continuation of the Choctaw fault southwestward to within about $3\frac{1}{2}$ miles of the intersection of its projection with that of the fault on the north flank of the Tishomingo anticline.

In 1928, Sidney Powers[7] reported that a well in Sec. 17, T. 4 S.,

[5] B. H. Harlton, oral communication.

[6] *Ibid.*

[7] Sidney Powers, "Age of Folding of the Oklahoma Mountains—the Ouachita, Arbuckle, and Wichita Mountains of Oklahoma and the Llano-Burnett and Marathon Uplifts of Texas," *Bull. Geol. Soc. America*, Vol. 39 (1928), p. 1045 (in footnote).

R. 11 E., about 10 miles south of Atoka, penetrated a section typical of the facies characteristic of the Arbuckle Mountains from Caney to Simpson, in other words a sequence characteristic of the segment that lies between the two faults. That well lies about 5 miles south and slightly east of the location of the Choctaw fault on Frounterhouse Creek. It seems apparent, therefore, that the Choctaw fault bends southeastward as it approaches the southeastward-trending granite nose and that a zone of strata of the facies characteristic of the Arbuckle Mountains lies between the Choctaw fault and the granite on the Tishomingo anticline. The exact distance through which the southeastward trend of the Choctaw fault continues is indeterminate but must be as much as 15 miles as it must pass between the well that encountered granite beneath Cretaceous strata about 12 miles east of Durant and the well that passed from Cretaceous strata into sediments of the facies characteristic of the Ouachita Mountains about 5 miles farther southeast (Fig. 1).

Strata of the facies characteristic of the Ouachita Mountains have been encountered beneath the Cretaceous rocks of the Coastal Plain in wells located about 6 miles west of Denison, Texas. The Choctaw fault has been placed immediately west of those wells by Miser and Sellards.[8] Therefore, the Choctaw fault must bend rather sharply westward somewhere southeast of the area in which gravity determinations were made, and a large reëntrant in the fault and the facies of rocks east of it must lie between Denison and Atoka. The exact location of the fault in that belt is indeterminate as neither data from gravity observations nor from wells are available.

It is probable that the relationship between the Choctaw fault and the south flank of the Tishomingo anticline is similar to that between the Choctaw fault and the north flank of the anticline. The anticline is bounded on the south by a fault similar to the one that forms the north boundary. According to subsurface data supplied by H. L. Griley[9] the south fault of the Tishomingo anticline continues to a point about 10 miles north-northwest of Durant and probably continues southeastward through and beyond Durant. On the basis of these data and the pattern of the iso-anomaly lines the reëntrant in the Choctaw fault is assumed to be essentially symmetrical (Fig. 1).

Robert H. Dott[10] has shown that there were two periods of folding

[8] H. D. Miser and E. H. Sellards, "Pre-Cretaceous Rocks Found in Wells in Gulf Coastal Plain South of Ouachita Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 7 (July, 1931), p. 807.

[9] H. L. Griley, oral communication.

[10] R. H. Dott, *op. cit.*, pp. 595–96.

on the Tishomingo anticline. The earlier folding occurred during the time of deposition of the Atoka formation of Pennsylvanian age. As the Atoka formation is conformable with underlying Pennsylvanian strata in most of the area east of the Choctaw fault, it is apparent that uplift on the Tishomingo anticline preceded the deformation of the Ouachita Mountain region and formation of the Choctaw fault. It appears probable, therefore, that the granite core of the Tishomingo anticline served as a buttress that either retarded the northwestward thrusting along a part of the Choctaw fault or elevated that segment so high that pre-Cretaceous erosion produced the reëntrant in the Choctaw fault. Late Pennsylvanian uplift of the Tishomingo anticline described by Dott[11] occurred after the formation of the Choctaw fault, which is believed to have taken place in middle Pennsylvanian time. Later uplift of the retarded or uplifted part of the overthrust side of the Choctaw fault would only have served to increase the depth of the reëntrant.

In conclusion, it may be stated that the gravity anomalies computed by the Coast and Geodetic Survey from their recent gravity determinations in southeastern Oklahoma show that the Choctaw fault has a deep southeastward-trending reëntrant coincident with the granite core of the Tishomingo anticline on the lower side of the fault.

[11] *Ibid.*, pp. 596–97.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 12 (DECEMBER, 1940), PP. 2150-2162, 8 FIGS.

ISOPACHOUS STUDIES OF ELLSWORTH TO TRAVERSE LIMESTONE SECTION OF SOUTHWESTERN MICHIGAN[1]

MARGARET STEARNS BISHOP[2]
Cassopolis, Michigan

ABSTRACT

The current wildcatting campaign in southwestern Michigan has revealed many irregularities in the interval between the "Red Rock" horizon at the base of the Coldwater formation of Mississippian age, and the Traverse limestone of Devonian age. It is the purpose of this paper to analyze these irregularities, and toward this end various isopachous maps and cross sections have been prepared. The results and conclusions derived from these studies are summarized as follows.

Regionally, the "Red Rock" to Traverse limestone interval thickens toward the west and northwest, due primarily to thickening of the Ellsworth formation, and possibly due to some thickening of the Antrim formation in these directions. Locally, the thickening off structure, which takes place throughout the complete section between the Traverse limestone and the Coldwater "Red Rock," tends to prevent minor structural or topographic irregularities on the surface of the Traverse limestone from being reflected in the overlying beds, and to minimize in the younger beds the degree of dip off the flanks of the larger structural features.

Evidence for the existence of an Ellsworth basin in southwestern Michigan is fairly definite, and the possibility that such a basin may have existed during the deposition of the Antrim formation is suggested.

Michigan has long been referred to as a synclinal basin, the center of the depositional basin being roughly the center of the lower peninsula. The results of recent drilling in southwestern Michigan suggest that in this part of the state a minor basin existed within the major basin probably from the end of Traverse (Devonian) time to the beginning of Coldwater (Mississippian) time. This basin became apparent from isopachous studies of the Ellsworth-Antrim section. The section studied comprises the group of shales lying between the Traverse limestone and the Coldwater "Red Rock."

Overlying the massive Traverse limestone in southwestern Michigan is a 60-foot section of gray shale which has been commonly referred to the Traverse formation. However, Hake and Maebius (1)[3] exclude this transition zone from the Traverse proper. Because it is largely composed of rock not of Traverse type they refer to the shale as a transition zone between the Traverse group and the Antrim formation, but do not more definitely place it in geologic time. The presence here and there of black stringers of shale at the base of this zone leads the writer to believe that the shale is more closely related to the Antrim formation above than to the Traverse limestone below.

[1] Read before the Association at Chicago, April 11, 1940. Manuscript received, July 1, 1940.

[2] Consulting Geologist, Bishop & Bishop, 203 S. East St.

[3] References indicate Bibliography at end of article.

Evidence of erosion (2) and weathering at the top of the limestone in southwestern Michigan further suggests a break between the limestone and shale periods of deposition, whereas the lenses of black shale interspersed in the upper parts of the gray shale indicate that no important hiatus occurs between the gray shale and the Antrim formation above it.

The Antrim formation is a black fissile shale 150–200 feet thick. Above the black shale is a zone of brown shale, which is followed by a series of alternating beds of green and brown shale, and finally by the Ellsworth greenish gray shale. The alternating beds of green and brown shale cause much confusion in determining the exact contact between the Ellsworth and Antrim formations, for aside from color the characteristics of the shale are similar.

The Ellsworth formation, which ranges from 250 to 700 feet in thickness, is delimited at the top by the red argillaceous dolomite which marks the base of the Coldwater formation according to present terminology. In some places the red dolomite is probably the weathered surface of the Ellsworth itself, but in other places it represents the reworked Ellsworth débris deposited by encroaching waters of the Coldwater sea.

In the lower part of the Coldwater formation red shale lenses of erratic vertical and horizontal distribution are present. These lenses appear to be more numerous on the eastern side of the area studied as well as off the flanks of structures, suggesting that duplication is due to gradual encroachment over islands which furnished source material after the lower surfaces had been covered. Above this red zone is a deposit of gray shale ranging in thickness from zero in the southwestern part of the area which is beyond the outcrop to 1,000 feet where it is fully present in northeastern Kent County.

The age of the group of shales between the Traverse limestone and the Coldwater "Red Rock" is still an unsettled problem. Ulrich (3) is said to have placed the beginning of the Mississippian period within the upper part of the Antrim black shales. Lane (4), however, placed the contact between the Mississippian and Devonian periods at the top of the Bedford, a formation which is missing in western Michigan, but which occupies in the eastern part of the state the same relative stratigraphic position as the Ellsworth. Ehlers (5) in view of recent information suggests that both the Antrim and Ellsworth may belong in the Devonian period.

Further paleontological studies are necessary before the question can be definitely settled, but on the basis of lithology alone the Ellsworth and Antrim appear to be closely related, and it is difficult to see

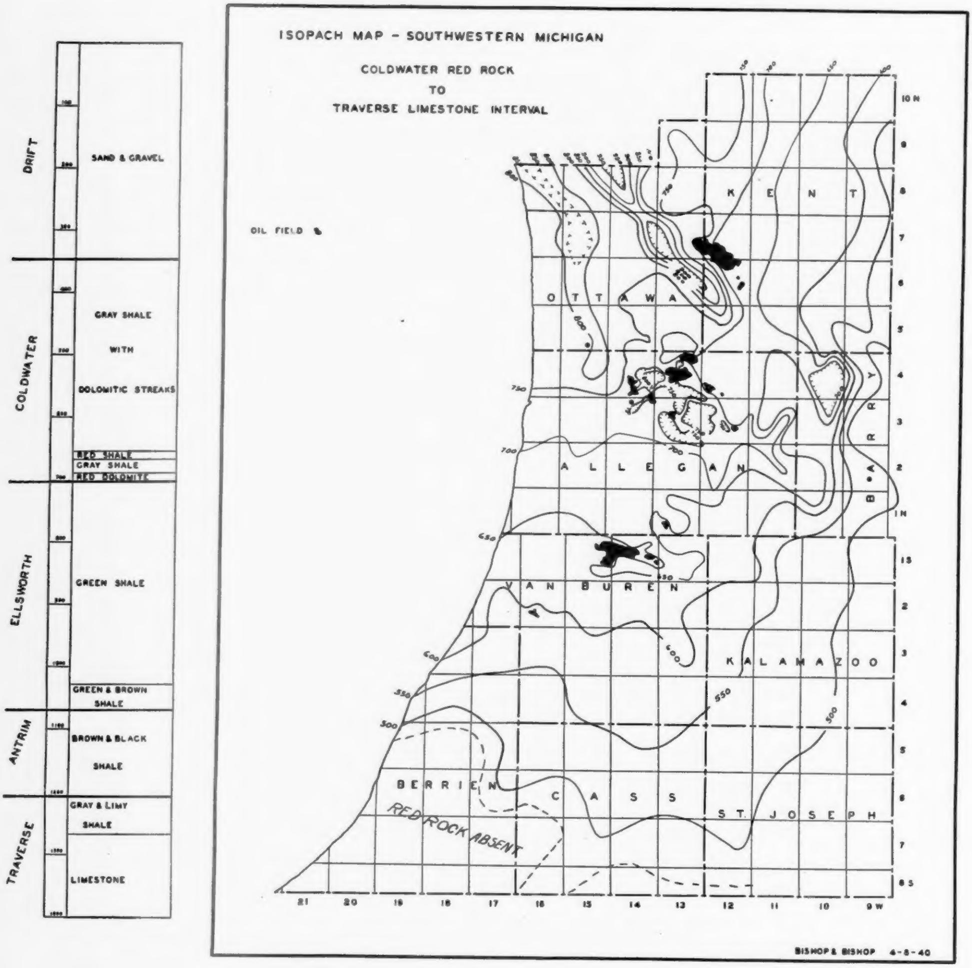


FIG. 1.—Isopach map of southwestern Michigan showing Coldwater "Red Rock" to Traverse limestone interval, and type log for southwestern Michigan.

how a major break, such as that between the Mississippian and Devonian periods can have taken place within this shale series.

Since the black color of the Antrim is due principally to the presence of mascerated organic material its gradual appearance and disappearance suggest a cycle of climatic changes during the deposition of the shale series. The transitional gray shale overlying the Traverse limestone may represent deposition during a cold, or a dry climate. With gradual increase in both humidity and temperature, vegetation became available for deposition with the muds, giving the Antrim its characteristic black or brown color. A period of increased aridity, during which the greenish gray Ellsworth shales were laid down, culminated in a withdrawal of the sea. Weathering and erosion followed, giving rise to widespread oxidation of the exposed Ellsworth formation. With the beginning of Coldwater time, southwestern Michigan was downtilted toward the northeast, and the minor basin lost its identity. From the northeast the Coldwater sea transgressed upon the exposed Ellsworth, incorporating its oxidized débris in the basal member of the Coldwater formation.

In central and eastern Michigan the Berea sandstone and Sunbury black shale were deposited between the Bedford, stratigraphic equivalent of the Ellsworth, and the Coldwater formation. These formations are mentioned because the Sunbury overlaps the Ellsworth in the northeastern and eastern part of the area studied. The Berea sandstone is not present, although a dolomitic phase of the upper Ellsworth has been referred to as "Berea" where it produces gas.

For the original study two isopach maps were made. The interval between the top of the red argillaceous dolomite, or Coldwater "Red Rock" and the top of the Traverse limestone was used for one, and the interval between the base of the Coldwater "Red Rock" and the top of the Antrim black shale was used for the other.

The isopach map of the Ellsworth formation was made in order to determine, if possible, whether the variations in thickness occurred in the Antrim, in the Ellsworth, or in both. It was found that both locally and regionally the major variations in thickness occur within the Ellsworth, with a suggestion of regional thickening within the Antrim formation as well. However, since samples were not available for Antrim correlations, and since the variations fall within a 50-foot range, this apparent thickening of the Antrim may be due to inconsistencies in determining the contact. Only the interval map of the whole shale series has been used for this paper because the top of the Antrim is too poor a key horizon for any conclusive deductions. The contouring of the two maps was so similar that the inclusion of both appears unnecessary.

On the "Red Rock" to Traverse limestone isopach map, the direction of thickening is toward the north and northwest, in contrast to

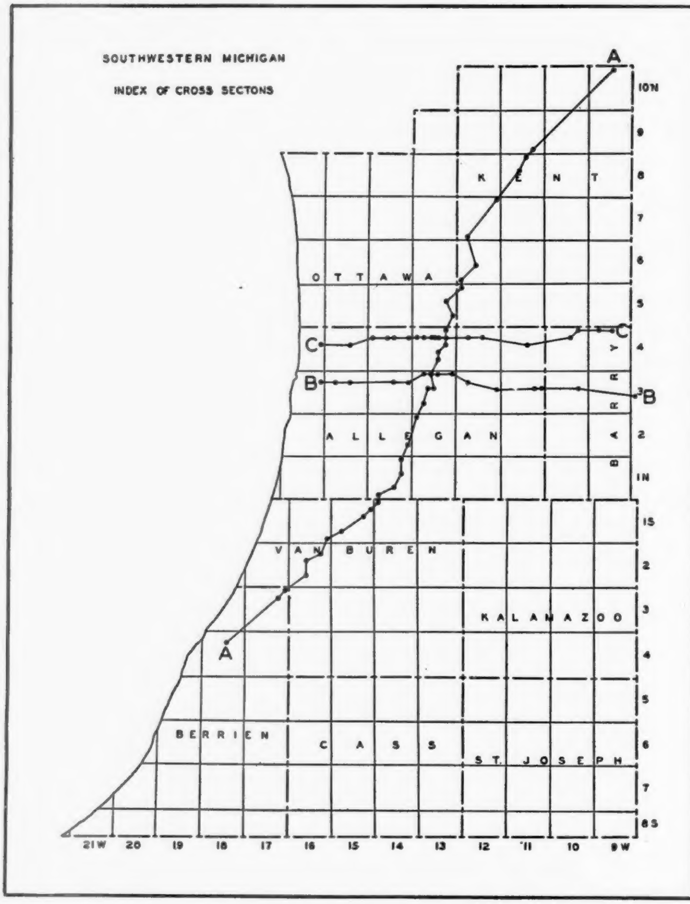


FIG. 2.—Index map of southwestern Michigan, showing locations of geological cross sections

the northeasterly direction of thickening which would be expected had the center of the depositional basin always been near the center of the lower peninsula.

The northeasterly direction of thickening for formations above the

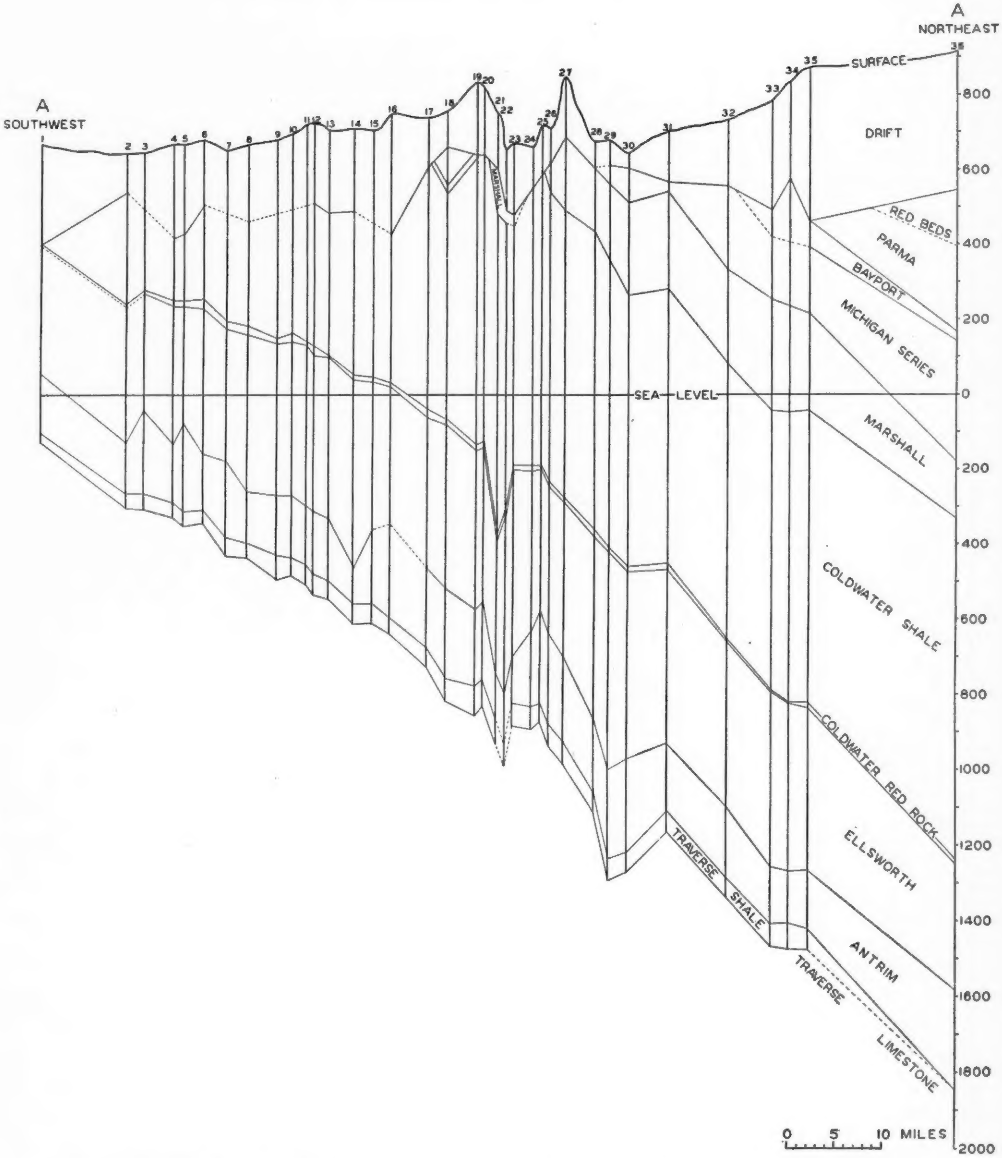


FIG. 3.—Section *AA*, northeast-southwest cross section of southwestern Michigan referred to sea-level.

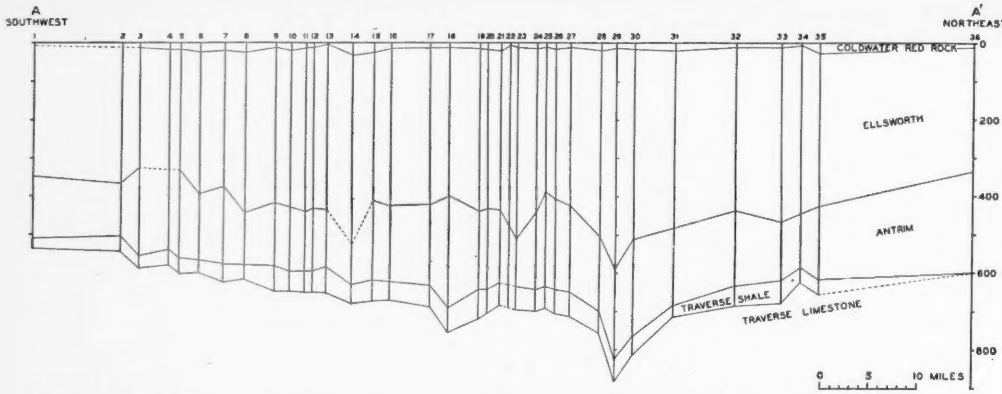


FIG. 4.—Section $A'A'$, northeast-southwest cross section of southwestern Michigan, referred to top of Coldwater "Red Rock," showing thickness variations between Coldwater "Red Rock" and Traverse limestone.

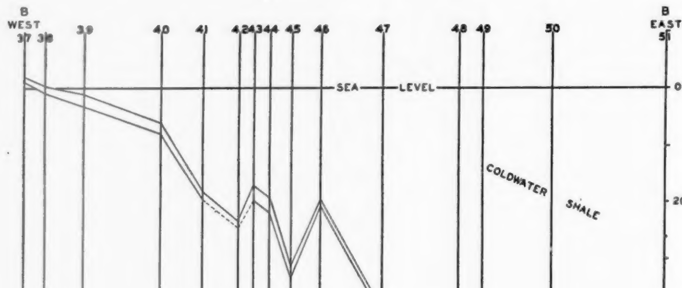


FIG. 5.—Section BB, east-west cross section through T. 3 N., R. 9–16 W., referred to sea-level, showing Coldwater "Red Rock" to Traverse limestone formations.

Coldwater "Red Rock" is well shown in section *AA*. This cross section, in which sea-level has been used as the datum plane, shows the entire group of formations from the Traverse limestone to the surface. It illustrates the loss by outcrop of the Michigan series, Bayport, and Marshall formations progressively toward the southwest, as well as the thinning of the Coldwater formation in the same direction. Section *A'A'*, in which the top of the Coldwater "Red Rock" has been used as a datum plane, shows only the thickness of the formations below

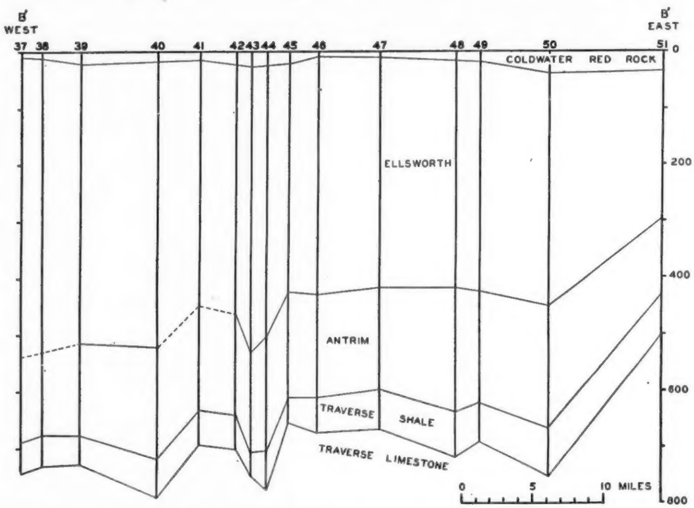


FIG. 6.—Section *B'B'*, east-west cross section through T. 3 N., R. 9–16 W., referred to top of Coldwater "Red Rock," showing thickness variations between Coldwater "Red Rock" and Traverse limestone.

the "Red Rock." It is apparent that the greatest amount of thickening for these lower formations occurs between Monterey Township (T. 3 N., R. 13 W.), Allegan County, and Walker Township (T. 7 N., R. 12 W.), Kent County.

Cross sections *BB* and *CC* are east-west sections traversing Townships 3 and 4 North, respectively, sea-level being the datum plane. Sections *B'B'* and *C'C'* traverse the same area, but are based on the top of the Coldwater "Red Rock" as a datum plane. These latter sections illustrate the thinning between the "Red Rock" and Traverse limestone in an easterly direction. Sections *BB* and *CC* show how the present direction of regional dip has been reversed with reference to the direction of thinning for the Coldwater "Red Rock" to Traverse limestone group of formations.

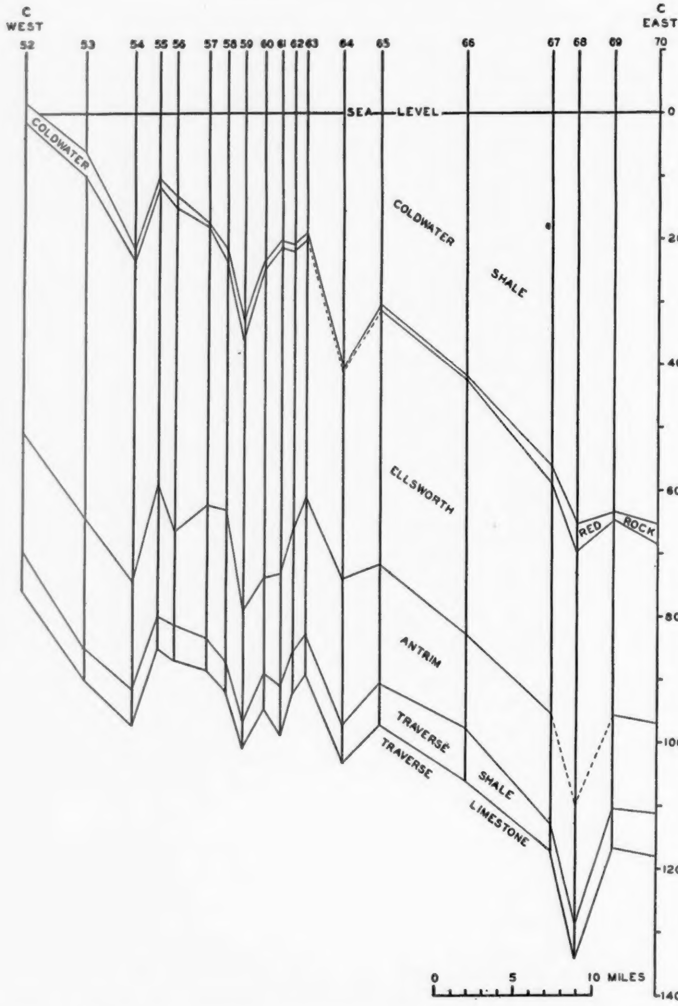


FIG. 7.—Section *CC*, east-west cross section through T. 4 N., R. 9–16 W., referred to sea-level, showing Coldwater "Red Rock" to Traverse limestone formation.

Northwest-southeast troughs, showing exceptional thicknesses of shale, occur in eastern Ottawa, in western Ottawa, and in north-central Allegan counties. The origin of these narrow troughs is uncer-

tain, but their existence at the end of Traverse limestone deposition is probable. At least for the troughs in Allegan and eastern Ottawa counties enough detail is available to ascertain that local thickening occurred not only in the Ellsworth, but also in the Antrim, and in the transitional gray shale zone below the Antrim.

The troughs may represent local erosional valleys, the steep slope

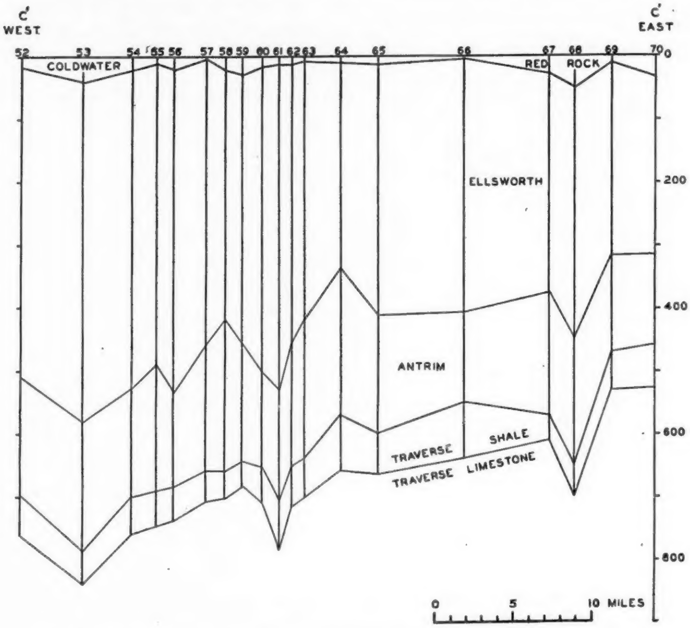


FIG. 8.—Section *C'C'*, east-west cross section through T. 4 N., R. 9–16 W., referred to top of Coldwater "Red Rock," showing thickness variations between Coldwater "Red Rock" and Traverse limestone.

off barrier reefs, or structural synclines, depending on the interpretation of the physiographic or structural features present on the Traverse limestone surface. It is significant that these major troughs flank the more pronounced "highs" on the limestone, and in the writer's opinion erosion has played an important part in emphasizing the presence of these low areas.

The presence of the troughs somewhat complicates interpretation of the isopach map, but it is apparent that from a regional standpoint thickening is present toward the north and northwest, even if the troughs are disregarded in the interpretation.

Newcombe (6) published an isopach map in 1933, showing the deepest part of the Ellsworth depositional basin to be in northwestern Michigan. The present study has not extended far enough north to determine the relationship between the deep troughs of southwestern Michigan and the basin on the northwest. Newcombe shows 600 feet of Ellsworth in the deepest part of the northwestern basin, whereas 650–700 feet are reported in recent wells in eastern Ottawa County. In areal extent, however, the northwestern basin is the more important.

On the same isopach map, in which Newcombe uses the Bedford section of eastern Michigan as comparable with the Ellsworth of western Michigan, a barrier is shown trending in a north-northeasterly direction, through central Michigan. Whether or not this barrier existed before Ellsworth time can not be determined at present. However, the fact that the transitional gray shale zone, lying above the Traverse limestone, is discontinuous toward the east suggests that a low barrier originated at the end of Traverse limestone deposition, becoming gradually more pronounced throughout Antrim-Ellsworth time.

The effect of the barrier on local accumulation in southwestern Michigan is not apparent at present. No oil has been discovered on the barrier itself, although it is now being tested by a few wells. Structures flanking the barrier, being closer to known production, are receiving more extensive exploration, and may result in discoveries before the end of the year. Production which has been discovered lies within the minor basin, in areas having a thinner "Red Rock" to Traverse limestone interval than the surrounding territory. Thus the isopach map serves a useful purpose in the search for new oil fields, as, in general, the areas of thin interval are regarded as most favorable for prospecting.

Thickening of the shale series off structure is sufficient to prevent minor structural or topographic irregularities on the surface of the Traverse limestone from being reflected in the more shallow overlying beds, and to minimize in the younger beds the degree of dip off the flanks of the larger structural features. For this reason, no key horizon above the Traverse limestone can be relied on to reflect structures in the Traverse. The use of the isopach map, in conjunction with a subsurface map contoured on the Traverse limestone, has been found helpful in overcoming this difficulty. For example, some wells which appear low on the Traverse subsurface map have shown enough shortening of interval to be the forerunners of a discovery. Other wells, located in the troughs, have been sufficiently high on the "Red Rock"

to cause unwarranted optimism among operators who had no isopach map for reference. Even with the use of the isopach map unpredictable irregularities in interval will continue to be found. Geologists in southwestern Michigan have the problem of an unconformable surface at the top of the Traverse limestone, and an even more apparent unconformity at the top of the Ellsworth formation. It is only by virtue, therefore, of the low cost of wildcatting that southwestern Michigan remains an attractive prospecting area.

WELLS USED IN GEOLOGICAL CROSS SECTIONS

	Well Number on Section	*State Permit Number*	*Sec.*	*T.*	*R.*	*County*
A	1	6,126	10	4 S.	18 W.	Berrien
	2	540	11	3 S.	17 W.	Berrien
	3	7,083	1	3 S.	17 W.	Berrien
	4	5,906	28	2 S.	16 W.	Van Buren
	5	5,686	16	2 S.	16 W.	Van Buren
	6	2,230	11	2 S.	16 W.	Van Buren
	7	6,352	36	1 S.	16 W.	Van Buren
	8	6,769	29	1 S.	15 W.	Van Buren
	9	5,889	14	1 S.	15 W.	Van Buren
	10	6,000	12	1 S.	15 W.	Van Buren
	11	6,195	6	1 S.	14 W.	Van Buren
	12	5,314	32	1 N.	14 W.	Allegan
	13	6,176	27	1 N.	14 W.	Allegan
	14	5,071	14	1 N.	14 W.	Allegan
	15	7,056	2	1 N.	14 W.	Allegan
	16	4,757	25	2 N.	14 W.	Allegan
	17	6,200	6	2 N.	13 W.	Allegan
	18	6,409	29	3 N.	13 W.	Allegan
	19	5,128	16	3 N.	13 W.	Allegan
	20	4,992	16	3 N.	13 W.	Allegan
	21	5,313	4	3 N.	13 W.	Allegan
	22	4,585	27	4 N.	13 W.	Allegan
	23	6,471	22	4 N.	13 W.	Allegan
	24	6,744	14	4 N.	13 W.	Allegan
	25	5,952	2	4 N.	13 W.	Allegan
	26	6,441	25	5 N.	13 W.	Ottawa
	27	4,928	14	5 N.	13 W.	Ottawa
	28	6,340	6	5 N.	12 W.	Kent
	29	6,529	31	6 N.	12 W.	Kent
	30	6,135	21	6 N.	12 W.	Kent
	31	5,207	32	7 N.	12 W.	Kent
	32	6,985	1	7 N.	12 W.	Kent
	33	6,260	16	8 N.	11 W.	Kent
	34	2,253	3	8 N.	11 W.	Kent
	35	4,835	35	9 N.	11 W.	Kent
A	36	3,496	3	10 N.	9 W.	Kent
B	37	6,814	12	3 N.	16 W.	Allegan
	38	6,854	8	3 N.	15 W.	Allegan
	39	5,538	10	3 N.	15 W.	Allegan
	40	5,064	10	3 N.	14 W.	Allegan
	41	5,716	12	3 N.	14 W.	Allegan
	42	4,979	5	3 N.	13 W.	Allegan
	43	5,106	4	3 N.	13 W.	Allegan
	44	4,935	3	3 N.	13 W.	Allegan
	45	5,026	1	3 N.	13 W.	Allegan
	46	5,378	8	3 N.	12 W.	Allegan

Wells Used in Geological Cross Sections—*Continued*

	Well Number on Section	*State Permit Number*	*Sec.*	*T.*	*R.*	*County*
	47	886	13	3 N.	12 W.	Allegan
	48	6,661	14	3 N.	11 W.	Allegan
	49	6,959	13	3 N.	11 W.	Allegan
	50	5,555	14	3 N.	10 W.	Barry
B	51	5,806	19	3 N.	8 W.	Barry
C	52	5,408	13	4 N.	16 W.	Allegan
	53	5,795	15	4 N.	15 W.	Allegan
	54	5,539	7	4 N.	14 W.	Allegan
	55	6,417	9	4 N.	14 W.	Allegan
	56	7,031	10	4 N.	14 W.	Allegan
	57	6,457	12	4 N.	14 W.	Allegan
	58	4,552	7	4 N.	13 W.	Allegan
	59	4,351	8	4 N.	13 W.	Allegan
	60	3,038	9	4 N.	13 W.	Allegan
	61	6,225	10	4 N.	13 W.	Allegan
	62	5,764	10	4 N.	13 W.	Allegan
	63	6,276	11	4 N.	13 W.	Allegan
	64	6,233	8	4 N.	12 W.	Allegan
	65	3,823	10	4 N.	12 W.	Allegan
	66	5,156	15	4 N.	11 W.	Allegan
	67	6,191	10	4 N.	10 W.	Barry
	68	5,990	2	4 N.	10 W.	Barry
	69	7,472	5	4 N.	9 W.	Barry
C	70	6,637	3	4 N.	9 W.	Barry

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4. Lane, A. C., and Seaman, A. E., "Notes on the Geological Section of Michigan," *Michigan Geol. Survey Ann. Rept.* (1909), pp. 73, 75.
5. Ehlers, G. M., University of Michigan, oral communication.
6. Newcombe, R. B., *op. cit.*, p. 78.

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WATER CONES AND WATER SHEATHS IN EXPERIMENTAL OIL WELLS[1]

F. B. PLUMMER[2] AND H. K. LIVINGSTON[3]
Austin, Texas, and Chicago, Illinois

ABSTRACT

The method of formation, shape, and characteristics of water cones and water sheaths, which form around experimental oil wells producing oil and water, are described, illustrated, and the effect of these features on the percentage of oil produced with the water illustrated graphically. It is demonstrated that the presence of water sheaths and cones tends to increase the proportion of water produced with oil. Three ways of reducing the vertical and lateral penetration of water into sand around experimental wells are discussed and illustrated. The relative effects of the three methods are shown, and the conclusion is reached that the percentage of oil can be increased and water production reduced by applying physical and chemical principles.

INTRODUCTION

Oil is associated with water in most oil fields, and in all water-drive oil reservoirs the oil wells begin to produce water sooner or later. The amount of water usually increases rapidly, especially in marginal wells, and after a few months the wells produce much more water than oil, even where it is known that at least 50 per cent of the pore space in the sand is still filled with oil. One would expect, without considering capillary effects and interfacial tension relationships between oil, water, and sand, that a fine-grained and uniform oil sand, completely penetrated by a well and having oil under pressure filling the upper half of the sand body and water under the same pressure filling the lower half, would yield the two liquids in about equal quantities. Or, at least, if the viscosity of the oil and the water were about the same, one would expect the well would yield about 50 per cent oil and 50 per cent water. As a matter of fact, laboratory experiments indicate that, under such conditions, and after the well has produced rapidly for some time, the yield will be more than 90 per cent water and less than 10 per cent oil. The reason for this high water ratio is thought to be the formation of water cones around the periphery of the well, and several methods of reducing the rapid penetration of water have been suggested. The problem of reducing the percentage of water produced with oil from marginal wells, however, is so important, that it has been thought worth while to make a study of radial flow of oil-water mixtures through sand with special reference to water ratios under different rates and methods of flow and with special reference

[1] Presented before the Association at Chicago, April 12, 1940. Manuscript received, June 13, 1940.

[2] The University of Texas.

[3] University of Chicago, formerly Shell Research Fellow, The University of Texas.

to the characteristics of water cones and water sheaths. The results of this experimentation are described in the following paragraphs.

CAUSES OF HIGH WATER RATIOS IN OIL WELLS

The researches of Wilde (25),[4] of Muskat and Wyckoff (13), of Wilde and Moore (24), and of others (9, 20) show clearly that when water and oil in the same sand are produced through a single well an increase in the rate of production increases the percentage of water due to the formation of a water cone around the periphery of the well. Water flows through the cone, and oil is excluded from the cone (Fig. 1). The results of the investigations of Garrison (6), of Bartell and

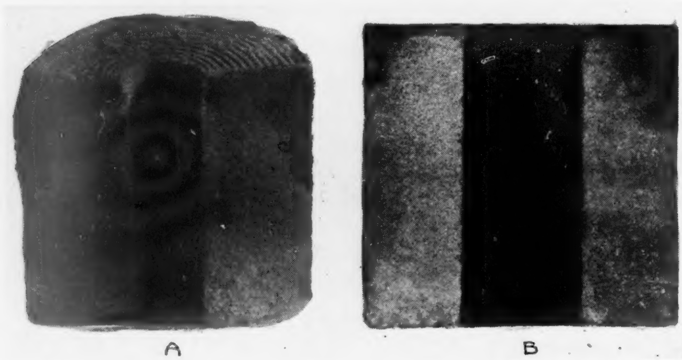

FIG. 1.—Vertical cross section through 2 cores: *A*, unconsolidated oil sand through which mixtures of oil and water have been flowing for more than 200 hours; *B*, limestone. Dark portion shows position of oil; light portion, position of water. Line *C* marks water-oil interface. Note cone shape of interface.

Miller (1, 2), of Plummer, Hunter and Timmerman (17), and those of Livingston (10) indicate that, in a very fine-grained sand with slow rates of flow, water produced with the oil tends to be drawn into the oil sand around the periphery of the well and around the periphery of the cone by capillary or wick action and forms a sort of water sheath between the oil and the well (Fig. 2). This tendency for sheath formation is particularly strong during shut-down periods, while a column of fluid is standing in the hole, and where water separates out below the oil in the bottom of the well. A sheath may form slowly, however, even during production, whenever water in the bottom of the well is in contact with the face of the oil and and when the reservoir pressure is low. Once a water sheath is formed around a producing well, water

[4] The numbers in parentheses refer to papers listed at the end of this article.

coming from the oil sand flows through the sheath, and oil tends to be excluded, just as in the case of a water cone. This action is due to the differences in interfacial tension between water and silica and that between oil and silica. The interfacial tensions between fluids and solids can not be measured directly. Accordingly, one is forced to rely upon the interfacial tensions between oil and water in studying the relative effectiveness of different waters to displace oil from capillary spaces. The interfacial tension between oil and water has been measured by Hocott (7) and by Livingston (11). The capillary force that

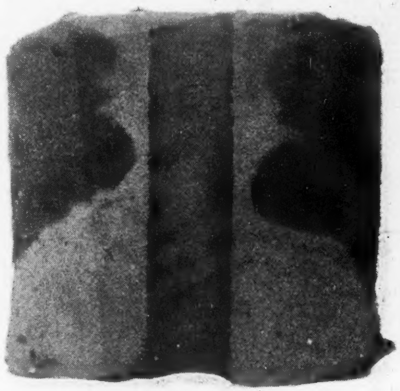

FIG. 2.—Vertical cross section of oil-sand core through which mixtures of oil and water have been flowing intermittently. Dark portion represents oil; light portion represents water. Note that water has penetrated sand around central hole and produced water sheath.

draws the water into the sand depends upon the size of the capillary spaces in the sand, the difference in density between the two liquids, and upon the sizes of the contact angle between the fluids and the rock surfaces (6, 3, 5). The contact angle, that is, the angle that the interface between the fluid phases makes at a solid surface, is a criterion of the degree to which a liquid will wet a solid. Thus, when a drop of oil is placed on a glass plate, it spreads out into a thin film; when a drop of water is substituted for the oil on the glass plate, it stands out as a small spherical droplet. In very fine capillary interspaces, and when assisted by some back pressure due to the head of a column of fluid in a well, this difference in wetting capacity, usually referred to as interfacial tension or capillary force, is sufficient to draw

water back into the sand around an oil well (6). If a well is producing rapidly and if the pore spaces in the sand are large, so that some of the voids are larger than capillary sizes (0.025 mm.), pinching of the well will reduce the size of the cone and will bring about a reduction of the percentage of the water. If the pore spaces are all very fine, as is characteristic of most fine-grained oil sand, then the water cone is held up in the sand by capillary forces and will not recede, and a further reduction in the rate of flow will not decrease the percentage of water to its original ratio. Slow production and shut-downs allow more time for oil and water to separate out in the well, hence fluid columns in the well become heavier, back pressure is increased, and the water separated out in the bottom of the column penetrates farther into the oil sand. Hence, whether an oil well produced rapidly or slowly, the percentage of water produced with the oil increases as long as water continues to penetrate laterally or vertically into the oil sand.

APPARATUS FOR EXPERIMENTAL WORK

The apparatus used for the study of water cones consists of five brass cylinders 7×15 inches in diameter, having flanged tops and connected with each other by three side tubes (Fig. 3). Each cylinder is connected also by means of manifolds with a compressor and with manometers. The pressure is controlled by means of regulators and a mercury relief valve. Brass pipes lead through the bottom and top plates into the interior of the cylinder (Fig. 4), and they may be connected with radial core holders (Fig. 5) in which the sand cores are securely sealed. The apparatus is so arranged that the fluid inside the cylinder flows rapidly through the sand in the core holders into the central hole or "well," which is inside the core, and then out through the tubing that connects the core holders with the outside of the cylinders. The tubing attached to the core holders can be either screwed into the openings in the bottom of the cylinders in experiments where downward withdrawal is desired or into the opening through the cover plate of the cylinders when upward or normal withdrawal of fluid is preferred. The fluid, as fast as it is produced and measured, is returned to the cylinders through the funnel in the top plate of the cylinder by opening and closing the proper valves. In this way the fluid levels are kept approximately the same in the cylinders at all times during the experiments. It has been possible by means of this apparatus to study the flow of oil-water mixtures through oil sands, to observe the effects of different water cones and water sheaths on the percentage of water produced, to study the effect of different detergent chemicals on water cones, and to compare water ratios in

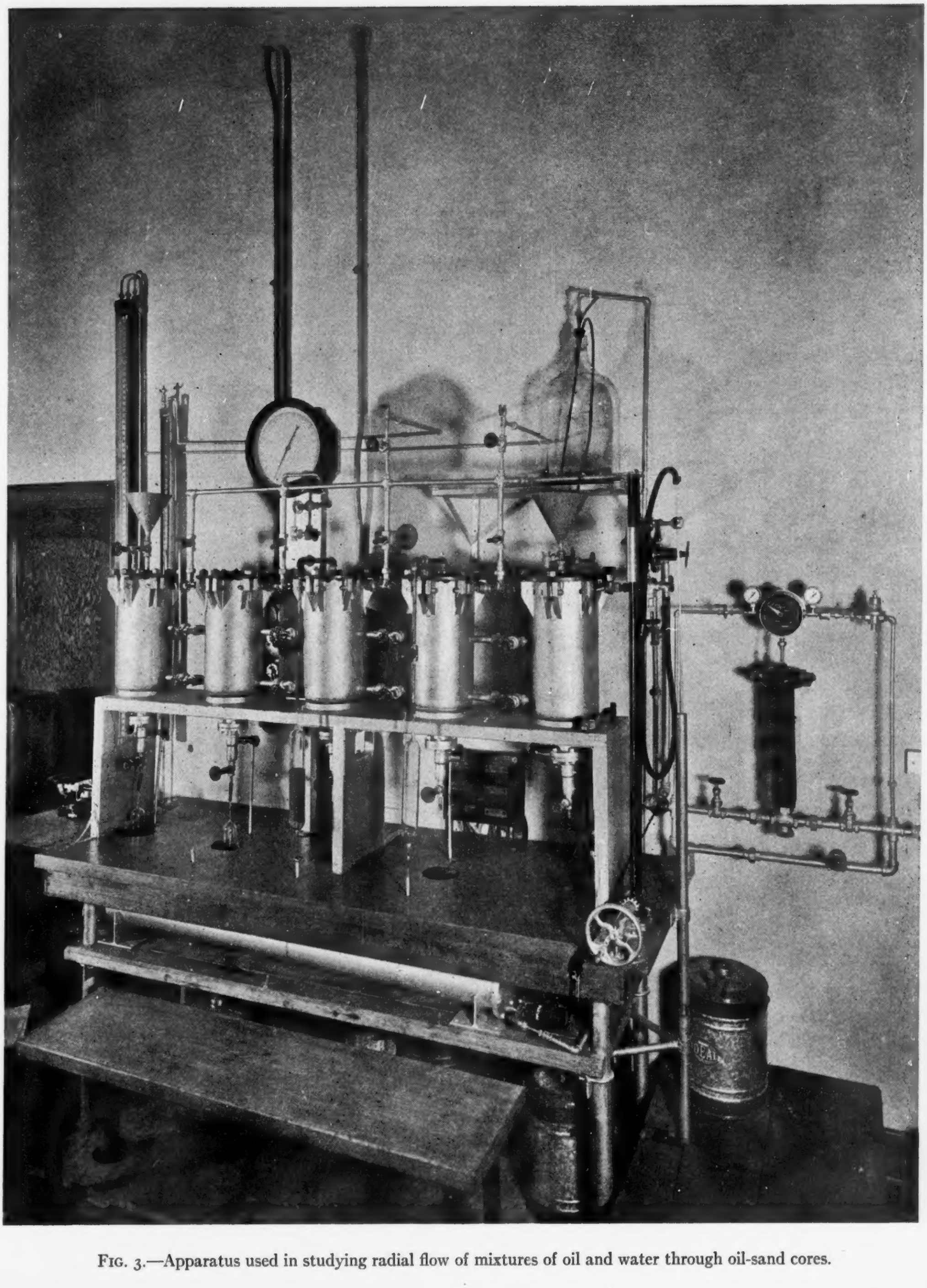

FIG. 3.—Apparatus used in studying radial flow of mixtures of oil and water through oil-sand cores.

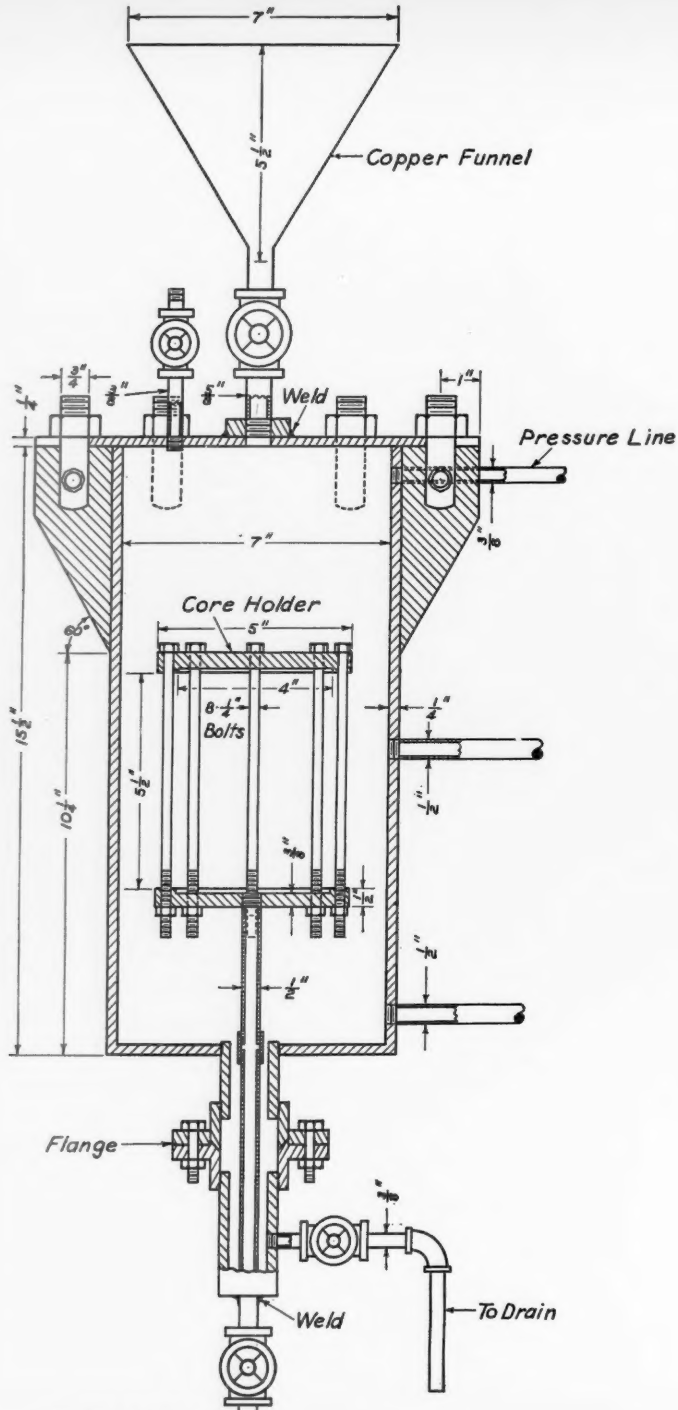

FIG. 4.—Cross section through cylinder of radial flow apparatus showing position of oil sand and arrangement of flow tubes for downward withdrawal of fluids.

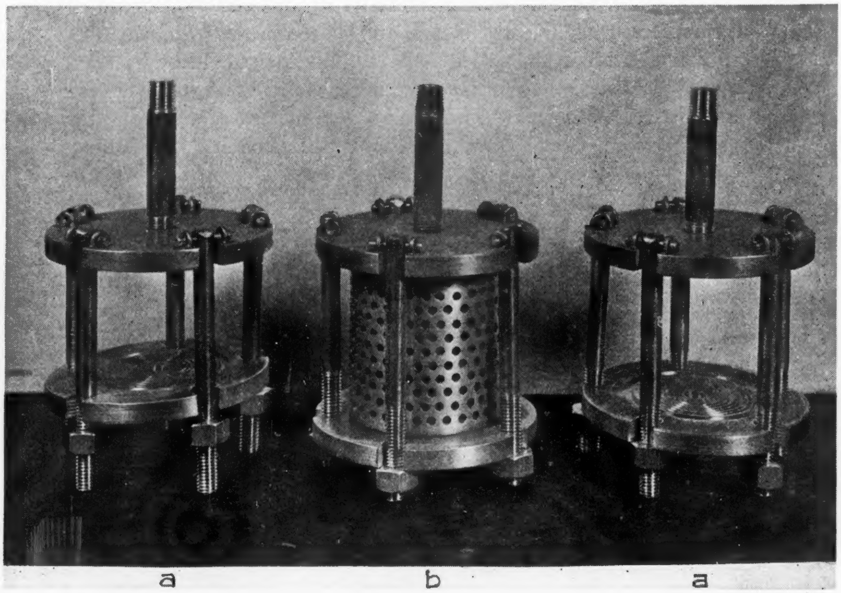

FIG. 5.—Core holders in which oil sand is sealed: *a* for consolidated sands; *b* for unconsolidated sands. Cylinder of fine (200-mesh) screen is placed inside perforated brass cylinder (*b*).

wells where the fluid was withdrawn downward with normal flows where the wells were produced upward.

EXPERIMENTAL WORK ON WATER RATIOS

Water ratios from fine-grained, unconsolidated sand under different rates of fluid production.—The core holders (Fig. 5) were filled with dry, water-free sand composed of grains between 0.0029 and 0.0035 inch (0.074 and 0.088 mm.) in diameter. The sand was saturated with oil, compressed in the core holders, and placed in the cylinders. The core holders were attached so that the fluid flow would be upward. The cylinders were then filled with a mixture of oil and water in such a way that the lower half of the sand was immersed in water and the upper half in oil. The oil came from the Salt Flats oil field near Luling, Texas, and had a gravity of 0.838 and viscosity of 8.25 centistokes at 29°C. The water was from the same field and had a gravity of 1.017 at 21°C. Air pressure was turned on the cylinders, and the oil and water obtained at different rates of flow were carefully measured. At first the well was allowed to flow under a differential pressure of one pound per square inch for 31 hours. The rate of flow was 1.8 cc. per minute. The percentage of oil was 15 per cent and that of water 85 per cent. The pressure in the reservoir was then increased to 5 pounds per square inch. The rate of flow increased to 100 cc. per minute, and at the end of one hour the percentage of oil was 5 per cent and that of water 95 per cent. The well was then shut down for 78 hours and pressure reduced once more to one pound. After 7 hours of flow the rate of production was 3.2 cc. per minute, of which 12 per cent was oil and 88 per cent water. The complete production data are shown in Table I. The sand core was removed from the apparatus, sliced vertically through the center, and the water-oil contact in the sand observed. A

TABLE I

Sam. No.	*Permeability, Millidarcys*	*Reser. Press., Lbs. per Sq. In.*	*Fluid Prod., Cc. per Min.*	*Time Elapsed, Hrs. Drg. Run*	*Total Time Elapsed, Hrs.*	*Percentage Oil at End of Run*	*Percentage Water at End of Run*	*Remarks*
12	2.41	1.1	1.8	2	2	70	30	Upward withdrawal
12	2.41	1.1	1.7	12	14	$15\frac{1}{2}$	$84\frac{1}{2}$	"
12	2.41	1.1	1.8	$16\frac{1}{2}$	$30\frac{1}{2}$	15	85	"
12	2.41	5.0	100	1	$31\frac{1}{2}$	5	95	"
Shut down for 78 Hours								
12	2.41	1.0	2.3	$1\frac{5}{6}$	$111\frac{1}{2}$	9	91	"
12	2.41	1.0	3.2	$7\frac{1}{6}$	$118\frac{1}{2}$	12	88	"
Shut down for 3 Months, 23 Days								
12	2.41	4.9	125	$\frac{1}{5}$	2,879	2	98	"
12	2.41	2.16	90	$\frac{1}{12}$	2,880	6.8	93.2	"

large water cone occupying the greater part of the sand around the "well" was clearly visible (Fig. 1).

It is clear from this experiment, as well as from experience in the oil fields, that increased rate of production increases the percentage of water produced with the oil by increasing the height of the water cone, and that after the increase has taken place shutting in the well does not reduce the water cone to its original level.

Water ratios from fine-grained, porous limestone under different rates of fluid production.—Cores of fine-grained, oölitic limestone were fitted into the core holder in such a way that the flow of fluids would be upward. The limestone cores were saturated with oil and immersed in the cylinders in such a way that the oil-water contact in the cylinders stood exactly halfway up the core. The same oil and water was

TABLE II

Sam. No.	*Permeability, Millidarcys*	*Reser. Press., Lbs. per Sq. In.*	*Fluid Prod., Cc. per Min.*	*Time Elapsed, Hrs. Drg. Run*	*Total Time Elapsed, in Hrs.*	*Percentage Oil at End of Run*	*Percentage Water at End of Run*	*Remarks*
14	2.41	42.5	1.94	7	7	72	28	Upward withdrawal
14	"	42.5	1.95	7	14	46	54	"
14	"	48	3.10	6¾	20¾	5	95	"
14	"	48	5.00	5	25¾	3.8	96.2	"
			Shut down 78 Hours					
14	"	47	6.00	1⅚	103¾	2	98	"
			Shut down 4 Months					
14	"	40	7.70	3¼	3,031¾	0	100	"

used as in the previous experiments. The pressure maintained on the cylinders was 48 pounds per square inch. The ratio of flow of oil and water through the cores at the end of 25 hours of continuous production was 5 cc. per minute. The percentage of oil was 3.8 and that of water was 96.2. After 78 hours the fluid flow was 5 cc. per minute, and the percentage of oil was 2 and that of water 98. At the end of four months the rate of production with a reservoir pressure of 40 pounds per square inch was 7.7 cc. per minute, the percentage of oil was zero and that of water 100. The complete data are given in Table II.

The limestone core was removed then from the core holder, washed quickly, and cut longitudinally into two sections by means of a carborundum saw. Except for a thin band at the top of the core, the entire limestone section appeared to be filled with water, which had obviously risen by capillary force into the limestone and had displaced the oil. It was clear that a cone and sheath of water formed around the hole had continued to increase in size during production and during

the shut-down interval, until the core was nearly completely saturated with water and became impervious to oil, so that water only was produced.

Water ratios from fine-grained sand under different modes of fluid withdrawal.—The core holders were again packed with fine-grained, water-free sand, having a grain size ranging from 0.0029 to 0.0035 inch (0.074 to 0.088 mm.). The sand was saturated with oil, placed in

FIG. 6.—Vertical cross section through unconsolidated, fine-grained sand in which fluids have flowed radially through sand and have been withdrawn through hole at bottom of core by method of downward withdrawal. Oil is in dark portion of core; water in light portion. Note oil-water interface has been drawn downward into funnel-shaped form. Sand has been broken in removing it from core holder.

cylinders, and connected with the opening in the bottom of the cylinder, so that the fluid would be drawn off downward. Oil and water in equal quantities were added to the cylinders in such a way that the upper half of the core was immersed in water and the lower half in oil. The reservoir pressure was regulated at 1.2 pounds per square inch. The rate of production after 19 hours of continous flow was 9 cc. per minute. The percentage of oil obtained was 19.7 and that of water 80.3. The pressure was then reduced to 0.8 pound per square inch and the cylinder was allowed to produce for 8 hours. The rate of flow was 3.17 cc. per minute. The percentage of oil was 20 and that of water 80. The complete data obtained during the run are given in Table III.

TABLE III

Sam. No.	Permeability, Millidarcys	Reser. Press., Lbs. per Sq. In.	Fluid Prod., Cc. per Min. (Aver.)	Time Elapsed, Hrs. Drg. Run	Total Time Elapsed, Hrs.	Percentage Oil Obtained (Aver.)	Percentage Water Obtained (Aver.)	Remarks
3	0.7	0.8	3.17	5	5	58.4	41.6	Downward withdrawal
Apparatus Shut in for 19.1 Hours, and Pressure Increased								
3	0.7	1.2	9.00	4	24.1	19.7	80.3	"
Apparatus Shut in for 44 Hours								
3	0.7	1.2	8.00	8	76	19.5	80.5	"
Similar Cores after Producing Total of 18 Hours Showed Following Ratios								
4	0.3	0.8	19.60	8	18	20	80	"

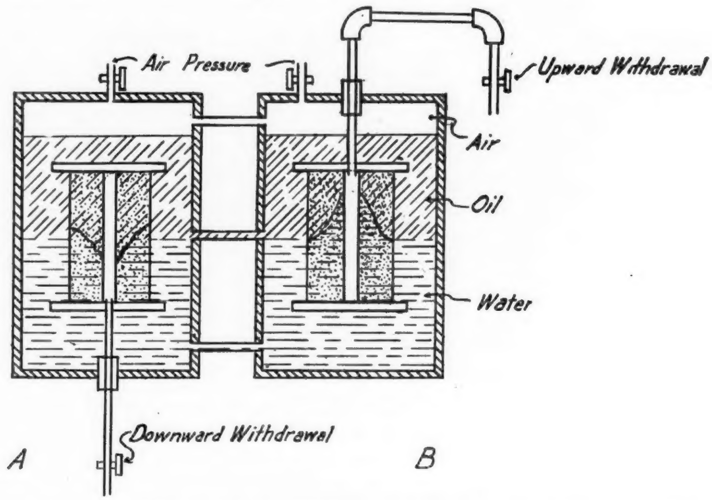

FIG. 7.—Diagram illustrating arrangement of apparatus for different modes of fluid withdrawal: *A* downward withdrawal; *B* upward withdrawal. Note that in *A*, water cone has formed around "well" and that in *B*, water cone is displaced downward and oil "funnel" occurs in its place.

After the experiment had been continued for 76 hours and no further increase in the percentage of water had taken place, the core was removed from the core holder, sliced, and the oil-water interface observed (Fig. 6). It was found that the oil-water interface had been drawn downward into a funnel or inverted cone and that the oil occupied a greater percentage of the interstices in the sand in this experiment than in the sand core in which the water cone was produced by upward withdrawal. A comparison of the two types of interfaces is illustrated in the diagram (Fig. 7). It is concluded that the method of

downward withdrawal yields a larger percentage of oil than the upward or normal method.

Water ratios in fine-grained limestone under different modes of withdrawal.—The core holders containing the unconsolidated sand in the apparatus were replaced by others containing fine-grained, oölitic limestone, which had been previously thoroughly saturated with oil. The pressure on the reservoir was maintained at 63 pounds per square inch, and the fluid withdrawal, as before, was downward. After 192½ hours the production was assumed to be nearly constant, at the rate of 1 cc. per hour. The yield of oil was 21 per cent and that of water 79 per cent. The complete data recorded during the flow period are shown in Table IV. At the end of the experiment the core was removed from the cylinder, sliced vertically through the center, and the water-oil interface observed. The interface between the oil and water was irregular but tended to be depressed near the center and to have a somewhat funnel-shaped appearance.

TABLE IV

Sam. No.	*Permeability, Millidarcys*	*Press., Lbs. per Sq. In.*	*Fluid Prod., Cc. per Min.*	*Time Elapsed, Hrs. Drg. Run*	*Total Time Elapsed, Hrs.*	*Percentage Oil*	*Percentage Water*
9	2	63	4.00	7	7	80	20
9	2	63	0.98	7.25	29.8	63	37
9	2	63	1.00	3.7	51.7	57	43
9	2	63	0.98	5.2	75.7	54.5	45.5
9	2	63	0.73	5	170.5	41	59
9	2	63	1.00	5	192.5	21	79

Comparison of upward and downward withdrawal.—The fine-grained oölitic limestone cores, after producing for 100 hours or more, yielded 2 per cent oil and 98 per cent water under a pressure of 63 pounds per square inch, when the fluid withdrawal was upward. The same limestone yielded 21 per cent oil and 79 per cent water when the flow was downward. A comparison of the results in the two different modes of production is shown in Table V. It is concluded from these results that downward withdrawals reduce capillary action around the periphery of the well and that the hydraulic forces tend to produce an oil

TABLE V

Sam. No.	*Permeability, Millidarcys*	*Press., Lbs. per Sq. In.*	*Fluid Prod., Cc. per Min.*	*Total Time Elapsed since Beginning Hrs.*	*Percentage Oil*	*Percentage Water*	*Remarks*
9	2	62	1	192.5	21	79	Downward withdrawal
14	2.2	48	5.2	199	2	98	Upward withdrawal

funnel instead of a water cone, and the result is that larger percentages of oil are produced.

Effect of detergent chemicals on oil-water ratios.—Another series of fine-grained oölitic limestone cores was placed in the core holders and connected inside the cylinders in such a way that the fluid production would be downward. Then equal quantities of oil and water were poured into the cylinders and a pressure of 63 pounds per square inch was applied. The mixture of oil and water was allowed to flow through the cores for 267 hours, when the ratio of oil to water produced was 15 to 85. This ratio continued to be fairly constant showing that the water had been drawn into the oil portion of the core as far as it was likely to penetrate. Then aerosol OT, a chemical that is known to have power to reduce markedly the interfacial tension between water and oil, was introduced into the water in the cylinder at a concentration of only 0.04 gram of aerosol per liter of water. A pressure of 63 pounds per square inch was then again applied to the cylinder, and the flow of liquids was allowed to proceed. At the end of one hour the percentage of oil had risen from 15 to 38.7 and that of water had fallen from 85 to 61.3. At the end of 100 hours production of the fluids was fairly constant with a yield of 68.4 per cent oil and 31.6 per cent water. Complete production data are given in Table VI.

TABLE VI

Sam. No.	*Pemea-bility, Milli-darcys*	*Press., Lbs. per Sq. In.*	*Fluid Prod., Cc. per Min.*	*Time Elapsed, Hrs. Drg. Run*	*Total Time Elapsed, Hrs.*	*Percentage Oil*	*Percentage Water*	*Remarks*
9	2	63	0.4	7	7	80	20	Downward withdrawal
9	2	63	0.6	3.1	265.6	15	85	"
Shut down 1.9 Hours and 0.04 Gr. of Aerosol OT Added per Liter of Water to Fluids								
9	2	63	1.3	1	268.5	38.7	61.3	"
9	2	63	1.38	6.6	326.1	68.4	31.6	"
Shut in 50 Hours								
9	2	63	0.89	15.5	395.5	93.6	6.3	"

Another experiment was started, using fine-grained, unconsolidated sand in place of the oölitic limestone. The sand was placed in the core holders, as before. The core holders were inserted into the cylinders and were connected so that the flow of the oil would be upward in the normal way. Equal quantities of kerosene and distilled water were added to the cylinder, and a pressure of one pound per square inch was applied. At the end of 72 hours the flow was fairly constant, the product being 5 per cent oil and 95 per cent water. Then 15 grams of Ivory soap flakes were added to 7 gallons of distilled water

in the cylinders. The percentage of oil increased from 5 to 68, and that of water decreased from 95 to 32, a most remarkable result, shown graphically in Figure 8. The time required to produce a given quantity of fluid, however, was almost doubled, indicating that the

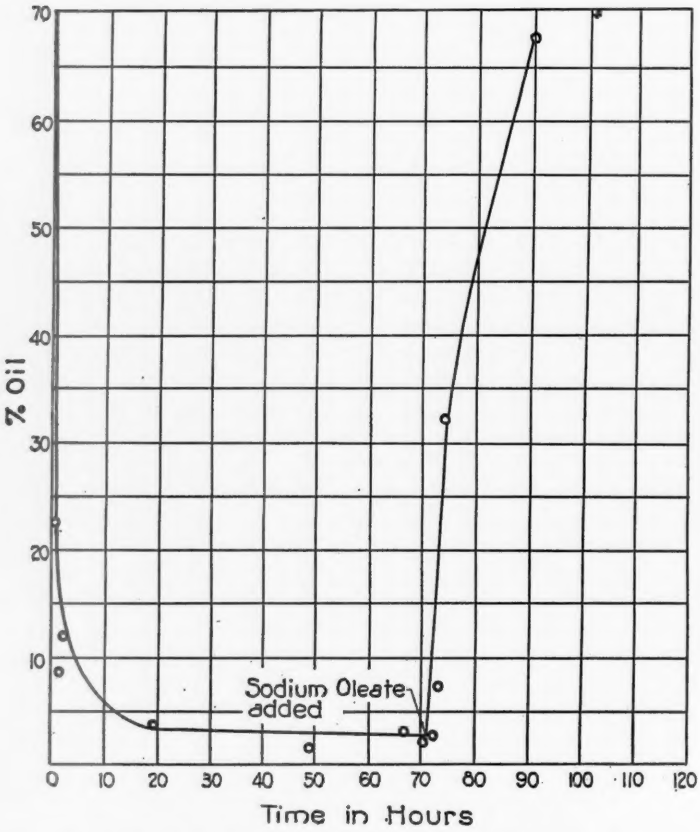

FIG. 8.—Graph showing effect of detergent chemical added to water on percentage of oil produced through sand.

permeability of the sand had been lowered. After the flow was concluded, the core was removed from the core holder and sliced. The water cone had disappeared (Fig. 9). In its place oil had migrated down into the lower part of the sand saturating a portion of the core. It is concluded that the interfacial tension of the water was so reduced

that water ceased to flow through the smaller capillary spaces. The percentage of oil, therefore, increased. The Ivory soap flakes were not successful in a mixture of oil and water obtained from the East Texas field, because the insoluble calcium soaps were precipitated by the mineral in the oil-field water. Aerosol OT and igepon AP, however, worked successfully and phenol to some extent. The data obtained when the igepon AP was used are shown in Table VII.

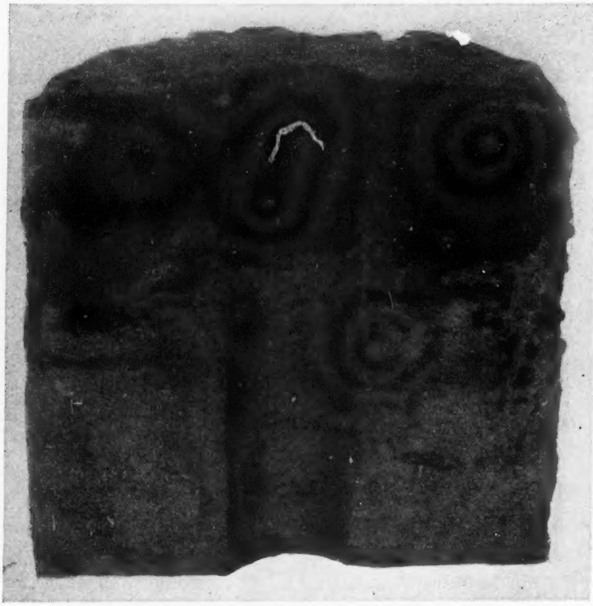

FIG. 9.—Vertical cross section of oil-sand core through which mixtures of oil and water have flowed for more than 200 hours and in which water has been treated with chemical to reduce interfacial tension. Dark portions are oil; light portions are water. Note that no water cone or sheath is present. Effect of chemical is readily seen by comparing this section with one in Figure 1.

The relative effectiveness of several interfacial reducing agents to reduce interfacial tension between oil and water in natural oil-water systems is shown in Table VIII.

CONCLUSIONS

These experiments as a whole indicate clearly how very significant in oil production is the presence of water cones and water sheaths

TABLE VII

Sam. No.	Permeability, Millidarcys	Press., Lbs. per Sq. In.	Fluid Prod., Cc. per Min.	Time Elapsed, Hrs. Drg. Run	Total Time Elapsed, Hrs.	Percentage Oil	Percentage Water	Remarks
3	0.7	0.7	10.2	0.8	141.9	20	80	Downward withdrawal
3	0.7	1.2	10	0.4	142.3	21	79	"
Shut down 2.7 Hours and 0.01 Gram Igepon AP/1 Added per Liter of Water								
3	0.7			1.4	1.4	35	65	"
Shut in 19.4 Hours								
3	0.7	1.2	3.57	3.5	24.5	57.5	42.5	"
3	0.7	1.2	3.85	5.3	481	46	54	"
3	0.7	1.2	3.34	4.7	70.1	50	50	"

TABLE VIII

Chemical Used	Interfacial Tension before Treating Dynes/Cm.	Mg. Added to 60 Cc. Sample	Interfacial Tension after Treating Dynes/Cm.	Interfacial Tension Lowering Dynes/Cm.
Igepon T	18	3	13	5
Igepon AP extra	18	6	3	15
Igepon AP extra	20	6	5	15
Phenol	20	6	10	10
Aerosol OT	20	6	2.5	17.5
Sodium hydroxide	18	6	12	6
W. A. Orvus flakes	20	20	3	17
Sodium (beta)-naphthalene sulfonate	20	1	13	7

around the peripheries of producing oil wells. They suggest ways in which the formations of such cones can be controlled. It is emphasized, however, that all conclusions reached apply to oil sands in the laboratory experiments and not to actual oil-field production. It is thought, nevertheless, that such fluid-flow experiments illustrate principles of water-cone and water-sheath behavior and the effect of detergent chemicals in fluid flow, which may lead to a better understanding of oil-sand conditions, and may possibly suggest new lines of approach to the solution of some of the water problems confronting production engineers.

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25. WILDE, H. D., JR., "The Value of Gas Conservation and Efficient Use of a Natural Water-Drive as Demonstrated by Laboratory Models," *Amer. Petrol. Inst. Prod. Bull. 210* (December, 1932), pp. 4-10.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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GEOLOGICAL NOTES

JONES COUNTY, TEXAS, DISCOVERY[1]

ORION A. DANIEL[2]
Wichita Falls, Texas

The King Oil Company's A. E. Olson No. 1 discovery well, $1\frac{1}{4}$ miles north of the Avoca pool, is located 330 feet from the north and west lines of the NE. $\frac{1}{4}$ of Sec. 189, BBB&CRR Co. Survey, Jones County, north-central Texas.

The well topped the so-called "Palo Pinto lime" at 3,204 feet and was drilled to a total depth of 3,236 feet, the lower part of the "pay" being the most prolific. The writer believes the pay zone is a reef limestone in the upper part of the Canyon series, and is not the Palo Pinto limestone as found in North Texas.

The area was mapped from subsurface control on dry holes drilled in the vicinity of the test. The writer began taking the block in 1937, soon after the discovery of the Avoca pool.

On the Railroad Commission test the well flowed 263 barrels of oil in 8 hours and 45 minutes through $\frac{3}{4}$-inch choke. The tubing pressure during the test dropped from 320 pounds to 70 pounds with a gas-oil ratio of 400 to 1. During the last 4 hours of the test, the well averaged 25 barrels of oil per hour.

J. B. LOVEJOY (Fort Worth, Texas).—The more or less critical problem developed by this note does not lie in the stratigraphic position of the producing zone, but rather the point is that the Palo Pinto limestone, where penetrated in subsurface, is rarely coincident in character and thickness with the section so named in its typical locality on the surface. The Palo Pinto limestone is thought in itself to be of reef origin and has been shown to grade from a limestone of several hundred feet thickness to a sequence of shales and sandy shales where traced in its lagoonal direction of deposition. In Haskell County, recent observation has disclosed a maximum development of 1,000 feet of limestone which includes the stratigraphic position of the Palo Pinto limestone and very nearly the thickness of the entire Canyon section.

[1] Manuscript received, October 19, 1940.

[2] Consulting geologist, 928 Hamilton Building, Wichita Falls.

MICROSCOPIC EXAMINATION OF PERMIAN CRUDE OILS[1]

RONALD K. DEFORD[2]
Midland, Texas

Professor W. A. Waldschmidt of the department of geology of the Colorado School of Mines, Golden, Colorado, is using the Sanders[3] method in studying crude oils derived from Permian rocks. Tiny fragments suspended in the crude petroleum are separated by means of an ammonium chloride filter and are examined under high magnification in search of animal and plant remains—spores and similar materials—that may suggest the source and history of the oil. The data obtained may help to test old theories or to frame new hypotheses.

Professor Walschmidt has already received a number of samples from West Texas. He needs more from widely separated places. Any oil man who can send him a sample of crude petroleum from Permian rocks or from rocks closely associated with Permian strata will be greatly aiding this research.

Quart samples are desired. The main point in taking a sample is to avoid contamination, especially from surface materials, such as pollen carried by the atmosphere. Therefore, samples should never be taken from tanks, but should be taken as near the well-head as possible. Recently reconditioned wells should be avoided; for example, wells in which tubing has just been pulled and re-run.

The quart bottles should be scrupulously cleaned before the sample is taken.

The following information about the sample is needed.

County	State	Field or area
Sample taken by whom?	Date taken?	
How taken?		
How long since well was reconditioned, tubing pulled, *et cetera?*		
Operator	Lease and number	
Location	Elevation	Total depth
Oil string set where? Cemented with how many sacks?		
Completion date		
How drilled in (with rotary tools circulating water *et cetera*)?		
Acidization and date		Shot and date
Production to date (rough estimate)		
Name of formation which contains producing beds		
Top and bottom of this formation		
Top and bottom of pay		

[1] Manuscript received, October 26, 1940.

[2] Editor, A.A.P.G. Permian volume.

[3] J. McConnell Sanders, "Microscopical Examination of Crude Petroleum," *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 167 (1937), pp. 525–73.

MIOCENE FISHES IN WELL CORES FROM TORRANCE IN SOUTHERN CALIFORNIA[1]

LORE DAVID[2]
Pasadena, California

INTRODUCTION

Although fossil fish and fish scales are abundantly preserved in Tertiary marine formations of California, little is known as to their value in stratigraphic correlation. To the present not much study has been made of such materials, and moreover the age limits of existence of the different types of fish in the Tertiary of the Pacific Coast have not been definitely established. The majority of Tertiary fish that have been described are upper Miocene in age. The Pliocene faunas, on the other hand, are either very incompletely known or have not been studied in detail.

We take occasion in this paper to report on determinable fish fossils preserved in well cores that come from two localities in the Torrance oil field of Los Angeles County. A fossil fish from a core was collected at a depth of 4,819 feet in well No. 1 of the F.S.D.R. Oil Company. This well is located on Lots 7 and 8, Tract 440, Torrance, 200 feet south of 240th Street and 500 feet east of Narbonne Avenue. The fish is preserved in a dark gray shale of the Modelo formation.

Several parts of well cores were taken from the McEwen well No. 1 of the Padran Oil Corporation, located at the northwest corner of 253rd Street and Petroleum Avenue in the so-called D and B area of the Torrance Oil field (C.I.T. loc. 363). Coring was begun at 5,100 feet and continued down to 5,300 feet. The fish-bearing sediments were obtained from approximately a 10-foot section of the core in the Modelo formation, having a position in the well from 5,193 to 5,203 feet. No distinguishable fish remains were observed either above or below this section.

Two relatively large core parts (No. 16112 U.S. Nat. Mus. Coll.) have a diameter of about 100 mm. One of these core samples is 15 mm. deep, and shows signs of fish remains throughout its depth. Two smaller discs of a core have a diameter of 60 mm. (Nos. 10148 and 10149 Calif. Inst. Tech. Coll. Vert. Paleon.).

DESCRIPTION OF MATERIAL

A single specimen from well No. 1 of the F.S.D.R. Oil Company represents a member of the Lanternfishes, family Myctophidae, and

[1] Manuscript received, November 2, 1940.

[2] Divison of the geological sciences, California Institute of Technology.

is determined as *Lampanyctus* sp. It probably belongs to the same species as that found in the core of the McEwen well of the Padran Oil Corporation, and measures 62 mm. in total length.

The following fishes are identified in the cores of the McEwen well in the Torrance area.

Family Myctophidae

Lampanyctus n. sp.

The best preserved material on the surface of the larger core represents three specimens of Lanternfish. One of these is nearly complete (Fig. 1), and measures 59 mm. in total length. Another well preserved specimen (tailpart) is visible on one of the smaller cores. The species is one which has been recognized in the fish fauna now being described from the lower member of the Modelo formation exposed along the northern rim of the Santa Monica Mountains, California.

Myctophum sp.

The fragmentary remains of a Lanternfish with deeper body than in *Lampanyctus* are present in another core-part. The characteristic scales of this family are more robust and are readily recognized in this specimen. They show regular circuli and 4–6 basal folds.

Family Bathylagidae

Bathylagus (*Quaesita*) *angelensis* Jordan and Gilbert

On a bedding plane slightly below that on which the three Lanternfishes are preserved is a specimen of an elongate flexible bathylagid fish referred to this species which measures 84 mm. in total length. A second fragmentary specimen, probably of the same form, is preserved in another core-part.

Family Clupeidae

Ganolytes cameo Jordan

A scale of this shad-like species is preserved on one of the smaller core-parts (No. 10149), its diameter measuring 16 mm. Scales of *Ganolytes* are very abundant in Miocene deposits of California and a similar scale attributed to *Pomolobus chicoensis* Cockerell has been described from the Chico formation of Upper Cretaceous age. These scales have a characteristic appearance with 4–6 paired wide-spaced transverse grooves and more or less numerous apical and basal radii; the middle area of the scales between the inner ends of the transverse grooves is often decorated with pointed elevations.[3]

[3] D. S. Jordan and J. Z. Gilbert, "Fossil Fishes of Southern California," *Stanford Univ. Pub.*, Univ. Ser. (1919), p. 6, Pl. IV.

SUMMARY

The fishes found in the well cores of the Torrance area are marine bathypelagical types, and, with the exception of the scales of the shad-like *Ganolytes*, indicate deposition at a depth of 200–1,000 meters. Although only a few specimens were obtained from the Torrance horizon by means of coring, the fossil fish comprising this assemblage can be correlated with a fauna from the upper part of the Modelo formation, as found on the northern rim of the Santa Monica Mountains. The Santa Monica fauna has been studied in detail and the report on this assemblage is now in press. It represents a small number of forms in which *Lampanyctus* n. sp. and *Bathylagus* (*Quaesita*) *angelensis* are predominant. A similar fauna is evidently available also at a locality in Sierra Vista (T. 1 S., R. 12 W., SE. $\frac{1}{4}$, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 5, Alhambra Quadrangle, U. S. Geol. Survey, 1939).

The present paper has been made possible by a grant from the Geological Society of America for a study of Tertiary fish faunas of the Pacific Coast. The writer is indebted to Dr. Chester Stock of the California Institute of Technology for advice and for a critical reading of the manuscript.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available, for loan, to members and associates.

GEOLOGY AND MINERAL RESOURCES OF WASHINGTON COUNTY, OKLAHOMA, BY MALCOLM C. OAKES

REVIEW BY JOSEPH L. BORDEN[1]
Tulsa, Oklahoma

"Geology and Mineral Resources of Washington County, Oklahoma," by Malcolm C. Oakes. *Oklahoma Geol. Survey Bull. 62* (1940). 208 pp., 18 tables, 19 figs., 3 maps.

As its title suggests, this volume is primarily about Washington County, but in reality it covers a geologic rather than a geographic unit. Work has been carried into adjoining counties wherever this seemed necessary, and nearly one-third of the area mapped lies outside of Washington County.

Stratigraphy occupies the most important place in the volume. Seventy-two pages are devoted to detailed descriptions of the surface rocks, all of which, with the exception of a few Quaternary deposits, are within the Missouri subseries of the Pennsylvanian. The stratigraphic detail of each unit, usually a formation, is given fully and carefully followed by the first reference, the nomenclator, the type locality, the original description, a history of usage, the distribution, the thickness, the character, the stratigraphic relations, and correlations. In addition references are given whereby all measured sections for each unit can be easily found in Appendix B, where 136 detailed measured outcrop sections are listed.

To complete the stratigraphic picture a brief résumé is given of the subsurface formations from the Des Moines subseries to pre-Cambrian granite.

A chapter describes the structure of the area and lists 17 anticlines and domes which were observed or have been described in print. A chapter on oil and gas resources lists the oil and gas pools and the important producing formations, and discusses future possibilities in the area. Several United States Bureau of Mines oil analyses are given.

In an effort to broaden the range of usefulness of the Geological Survey's publications there are 33 pages devoted to mineral resources in the area other than oil or gas. These range from limestone and phosphate through sulphuric acid to underground water. Data on 808 water wells are given.

There are three plates in the pocket of the volume. Plate I is a geologic map of the area drawn on a scale of one inch to one mile. Mr. Oakes has gone a step beyond the usual geologic map and shows by symbol where the best exposures of the various rocks are located. The map also shows all drainage and all roads. Plate II is a composite outcrop section, while Plate III is a production map of Washington County reproduced without change from Oklahoma Geological Survey *Bulletin 19*, Part II (1917).

Bulletin 62 will be greatly appreciated by all who have had any contact with the surface geology of northeastern Oklahoma. It is particularly helpful in clarifying that section in the middle Ochelata group where the sandstones and limestones above the Avant (Iola of *Bulletin 62*) limestone have long been confused in the minds of local geologists.

[1] The Pure Oil Company. Manuscript received, October 29, 1940.

It is inevitable that a few minor errors and mistakes should creep in. Mr. Oakes credits the writer with the discovery of an inlier of Hogshooter limestone in the SE. ¼ of Sec. 17, T. 26 N., R. 13 E., near Bartlesville, whereas this is shown by Ohern on the unpublished maps of the Nowata-Vinita quadrangles.

It is to be hoped that *Bulletin 62* is the first of many volumes which will discuss in similar detail the geology and mineral resources of other counties or geologic units.

CALIFORNIA FOSSILS FOR THE FIELD GEOLOGIST, BY HUBERT G. SCHENCK AND A. MYRA KEEN

REVIEW BY ROBERT T. WHITE[1]
Bakersfield, California

California Fossils for the Field Geologist, by Hubert G. Schenck and A. Myra Keen. Preliminary edition (1940). 86 pp., 62 pls. Paper. Price, $2.00 ($1.03 to students). Copies for sale by Hubert G. Schenck, Box 1528, Stanford University, California.

The purpose of this preliminary edition is to make available to the California geologist, for field use, a compact handbook of diagnostic Tertiary fossils, plus a few from the Upper Cretaceous and Jurassic. The dimensions of the book are 5½ inches by 8½ inches, with a spiral binding at the top.

Plates 1–16 illustrate the morphology of a number of different genera, and on many of these illustrations various morphological features of the shells are labelled. Plates 17–62 contain figures of faunal assemblages common to particular formations ranging in age from Jurassic to Recent. Two hundred thirty-two species are figured from the Tertiary, and 24 and 1 are figured from the Upper Cretaceous and Jurassic, respectively.

The fossils are cross-indexed by genera, species, and formations. On the last two pages is a correlation chart of the Tertiary formations from which the fossils were illustrated.

The compactness of this book readily lends itself to field use. The arrangement of the fossils by assemblages, and an adequate index, should prove a boon to the geologist in making necessary identifications in the field.

[1] Barnsdall Oil Company. Manuscript received, October, 1940.

GEOPHYSICAL PROSPECTING FOR OIL, BY L. L. NETTLETON EXPLORATION GEOPHYSICS, BY J. J. JAKOSKY GEOPHYSICAL EXPLORATION, BY C. A. HEILAND

REVIEW BY PAUL WEAVER[1]
Houston, Texas

Geophysical Prospecting for Oil, by L. L. Nettleton. McGraw-Hill Book Company, Inc., New York (July, 1940). XI+444 pp., 177 figs. $5.00.

Exploration Geophysics, by J. J. Jakosky. Times-Mirror Press, Los Angeles (July, 1940). XII+786 pp., 411 figs. $8.00.

[1] Chief geophysicist, Gulf Oil Corporation. Manuscript received, November, 1940.

Geophysical Exploration, by C. A. Heiland. Prentice-Hall, Inc., New York (October, 1940). XIII+1,013 pp., 636 figs. $10.00.

The practically simultaneous publication of three treatises on applied geophysics is perplexing to this reviewer. With practical experience, both in the field operations and in the exposition before students and operators, he had been hoping for a book on applied geophysics more detailed and more recent than the last ones in English (Eve and Keyes, 1929, and Broughton, Edge, and Laby, 1931.) That three outstanding members of the profession should fulfill this hope, so long deferred, seems like a sudden embarrassment of riches. Although comparisons may be sometimes odious, a study of the three volumes indicates that they are all pertinent, and, although perforce there are many fundamental principles of geophysics of which the theory is repeated from one book to another, the respective authors have treated the application of those principles in field measurements and in interpretation, each in his own way, with sure, accurate, and facile language, so that each should appeal to a particular audience, depending upon their previous education and their interest in the details of instruments and interpretation.

Dr. Nettleton states in his preface:

> The present work is intended for the student or lay reader rather than the geophysical specialist. . . . The book is the outgrowth of a course of lectures grown for several years at the University of Pittsburgh, chiefly for students in petroleum geology and petroleum engineering. It is designed for those with a geological rather than a physical background.

His book is therefore one which will appeal to the petroleum geologist as an introduction to the subject, because of the clarity and simplicity which result from the demonstration of principles by the use of ideal and simple cases, and also because the detailed description of instruments and of field technique has been restricted to the types in most accepted use. To those desiring to follow any particular aspect in more detail, there is appended to each chapter a chronological list of the literature mentioned in the text. Study will show that these references have been carefully selected, and they include the outstanding presentations of the respective subjects.

The simplicity of treatment is successful, in part, because the comparison of different methods is kept in view; in part, because the treatment of field methods is reduced to the essential steps for each procedure. It therefore includes all material necessary for an understanding of both the principles and operating methods used in geophysical work for oil companies, without considering the modifications needed for individual regions and for special problems.

Dr. Jakosky has taken a broader field, and the scheme of presentation is somewhat different. As he states in the preface of the book:

> The chief object of this book is to describe the fundamental theories, equipment and field techniques of the recognized exploration geophysical methods, and to illustrate their application to problems of economic geology.

The book therefore includes the geophysical survey of metallic deposits as well as of structures which might contain oil. The method of treatment of each geophysical method is to discuss the theory, the equipment, and the field procedure, in considerable detail, so that various alternatives are ap-

praised. As to interpretation, the derivation of many working formulae are explained, and there are illustrative examples, not only for ideal cases but also of particular surveys, both for oil regions and for metallic deposits. Instead of a bibliography, each chapter has a list of patents pertinent to the subject matter of the chapter. The maps showing actual field-survey results are accompanied in most cases by geologic cross sections and by a short discussion of the results.

Dr. Jakosky's book therefore is of wider appeal than Dr. Nettleton's because it discusses a wider field of applications, and also because it goes into alternative and special types of equipment and procedure. It is therefore written more for the specialist, and will appeal especially to those who actually conduct geophysical surveys. The many illustrations of equipment are well chosen to hold the interest of crew men and to attract the general reader. It is valuable therefore as a case book.

In Dr. Heiland's book there is a dual arrangement. Part I describes briefly the applications of geophysics to different economic fields, and in 64 pages presents:

> Written in elementary language. . . . the working principles and geological applications of geophysical methods. (Preface v)

Nowhere has applied geophysics been described so succinctly, and every geologist should read this Part I.

In Part II, each method is discussed according to a uniform plan. To quote the Preface again (page vi):

> First is an outline of fundamentals, followed by a description of rock properties and rock-testing methods. Instruments and instrument theory, as well as corrections and interfering factors, are reviewed next. The treatment is concluded in each case with a derivation of the fundamental interpretation equations and a description of surveys made on known geologic conditions.

In each chapter a uniform set of symbols is used in all of the mathematical treatment, and the final working formulae are usually shown without showing every step in their derivation, except in the case of the torsion balance. This abbreviation has reduced the algebraic content, and has enabled a greater number of the formulae to be given; all who have occasion to compute or study computations of geophysical results will be grateful for the compilation in a single book of so many of these formulae and the respective graphs.

To those interested in design of equipment, the book is also valuable as a reference manual.

The illustrative cases of actual surveys are representative, and like all of the graphs and other figures, have been very clearly drafted, as can be appreciated especially in those drawings adapted from various original articles.

One feature of timeliness is the consideration given to applications of geophysics to military engineering. It is unfortunately a duty of all geologists and geophysicists at this time to consider how their special experience and training can be applied in this field, and it is earnestly recommended that the respective paragraphs of the book concerning military applications be studied.

To each of the authors we must pay tribute for the great labor which the books represent. Each is recognized for his past contributions to research, each has now gained recognition as a commentator, giving us in these books a recapitulation of past performance, as a guide for future field work and interpretation in geophysics.

RECENT PUBLICATIONS

ALBERTA

*"Prairies and Foothills Have Many Inadequately Tested Attractive Structures," by J. O. G. Sanderson. *Canadian Oil and Gas*, Vol. 1, No. 4 (Toronto, October, 1940), pp. 8–11; 3 figs., 2 photographs.

ARGENTINA

*"Geological Study of the Province of Córdoba," by H. G. Bain Larrahona. *Bol. Inform. Petrol.*, Vol. 17, No. 192 (Buenos Aires, August, 1940), pp. 13–53; 16 figs., 59 photographs. In Spanish.

BRAZIL

*Geological Map of Brazil and Parts of Adjoining Regions, by Avelino Ignacio de Oliveira. *Brazilian Bur. Fuels and Minerals* (Rio de Janeiro, 1938). One sheet in 15 colors or colored symbols, 28.5×27.5 inches. Scale, 1:7,000,000. Shows oil localities. In Portuguese.

*"Age of Calumbí Limestone (Sergipe)," by Paulo Erichsen de Oliveira. *Brazilian Div. Geol. and Min. Avulso 19* (Rio de Janeiro, January, 1940). 12 pp., 2 pls. of fossils. "A preliminary note concerning five very interesting fossils, collected by Dr. Aristomenes Duarte, in the upper stratigraphic member of the Cretaceous formations of Sergipe . . . " Various considerations induce the author to assign Maestrichtian age to the higher beds of the Cretaceous column of Sergipe, located in the central part of the "Northern Petroliferous Province of Brazil." In Portuguese.

*"Geology of the Eastern Baía Basin," by José Lino de Melo Junior. *Ibid., Avulso 20* (February, 1940). 12 pp., 1 map. The author separates "the gneiss from the Tertiary and Cretaceous sediments . . . He obtained sufficient evidence that the crystalline area on the eastern side of the 'Baía Basin' is much broader than was supposed up to the present, and therefore restricted considerably the area of interest for petroleum researches."

*"Stratigraphy of Coals of San Catarina," by José Fiusa da Rocha e Evaristo Pena Scorzo. *Ibid., Bol. 104* (1940). 162 pp., illus. A revision of I. C. White's geologic column of Gondwana formations of southern Brazil. In Portuguese. English summary, pp. 5–7.

CALIFORNIA

*"Future Oil Possibilities of Newhall-Castaic District," by David Wosk. *Oil and Gas Jour.*, Vol. 39, No. 23 (Tulsa, October 17, 1940), pp. 24–26; 1 photograph, geologic map and cross section.

*Oil Possibilities of Newhall-Castaic Area," by L. David Wosk. *Petrol. World*, Vol. 37, No. 10 (Los Angeles, October, 1940), pp. 22–27; 3 figs.

COLOMBIA

*"The Bogota Fault, Colombia, South America," by Thomas Clements. *Jour. Geol.*, Vol. 48, No. 6 (August-September, 1940), pp. 660–69; 3 figs.

EAST INDIES

Geological Expedition to the Lesser Sunda Islands under the Leadership of H. A. Brouwer, Vol. 1 (1940). 348 pp., illus. Noord-Hollandsche Vitgevers Maatschappij, Amsterdam; Nordeman Publishing Company, New York. Price, $8.40.

GENERAL

*"A Method for Determining the Water Content of Oil Sands," by D. B. Taliaferro and G. B. Spencer. *U. S. Bur. Mines R. I. 3535* (September, 1940). 11 multigraphed pp., 1 fig., 3 tables.

Exploration Geophysics, by J. J. Jakosky. 786 pp., 411 figs., 23 tables. 6×9 inches. Cloth. "The chief object of this book is to describe the fundamental theories, equipment and field techniques of the recognized exploratory geophysical methods, and to illustrate their application to problems of economic geology." Times-Mirror Press, Los Angeles, California. Price, $8.00.

Sedimentary Petrography, by Henry B. Milner. 3d ed. (1940). 666 pp. (601 pp. of text and illus.; 13 pp. of lists of minerals; 24 pp. of bibliography; 28 pp. of subject and author index); 100 text figs.; 52 pls., 5.5×8.5 inches. Cloth. Special reference to petrographic methods of correlation of strata, petroleum technology, and other economic applications of geology. Thomas Murby and Company, 1 Fleet Lane, E. C. 4, London; Nordeman Publishing Company, Inc., 215 Fourth Avenue, New York City. Price, $10.00.

*"Conservation of Oil and Its Seamy Side," by R. E. Collom. *Oil Weekly*, Vol. 99, No. 6 (Houston, October 14, 1940), pp. 12–23; 5 photographs.

**Annotated Bibliography of Economic Geology for 1939*, Vol. XII, No. 2 (August, 1940), pp. 177–340; petroleum and natural gas, pp. 635–791. Prepared under the auspices of the Society of Economic Geologists. Published by the Economic Geology Publishing Company, Urbana, Illinois. Price, $5.00 per year.

**Geophysical Exploration*, by C. A. Heiland. 1,013 pp., 539 figs., 86 tables. 6×9 inches. Cloth. "This book is intended as a comprehensive survey of the entire field of geophysical exploration."—From the Preface. Prentice-Hall, Incorporated, 70 Fifth Avenue, New York City (1940). Price, $10.00.

*"Measurements of Compressibility of Consolidated Oil-Bearing Sandstones," by Charles B. Carpenter and George B. Spencer. *U. S. Bur. Mines R. I. 3540* (October, 1940). 20 multigraphed pp., 5 figs., 1 table.

*"Some Geological Factors Concerning Our Future Oil Reserves," by A. I. Levorsen. *I.P.A.A. Monthly*, Vol. 11, No. 7 (Tulsa, November, 1940), pp. 27–30; photograph.

**Report of the Committee on the Measurement of Geologic Time, 1939–1940*, by Alfred C. Lane, chairman, John Putnam Marble, vice-chairman, *et al.* 141 multigraphed pp. National Research Council, 2101 Constitution Avenue, Washington, D. C. (September, 1940).

ILLINOIS

Oil and Gas Map of Illinois (revised, August 1, 1940). 30×51 inches. Scale, 1 inch = 8 miles. Three colors: black base, blue drainage, and red overprint showing location of oil and gas fields, pipe lines, pumping stations, and refineries. State Geological Survey, Urbana, Illinois. Price, $0.35.

KANSAS

*"Geology and Ground-Water Resources of the 'Equus Beds' Area in South Central Kansas," by Stanley W. Lohman and John C. Frye. *Econ. Geol.*, Vol. 35, No. 7 (November, 1940), pp. 839–66; 5 figs., 2 tables.

LOUISIANA

*"Preliminary Report on Ground-Water Conditions at Alexandria, Louisiana," by John C. Maher. *Louisiana Geol. Survey Pamphlet 2* (New Orleans, June, 1940). 54 pp., 3 figs., 1 pl., 2 tables. Prepared in coöperation with the U. S. Geol. Survey.

MONTANA

*"Structure of the Pryor Mountains, Montana," by D. L. Blackstone, Jr. *Jour. Geol.*, Vol. 48, No. 6 (August-September, 1940), pp. 590–618; 15 figs., 1 table.

MICHIGAN

*"Southwestern Michigan." In "Well Logs and Field Data of Active Oil Areas," compiled by *Oil and Gas Jour.*, Vol. 39, No. 24 (Tulsa, October 24, 1940). 2 pp., geological map and log sections in colors.

NEBRASKA

*"Falls City Pool, Richardson County, Nebraska." *Oil and Gas Jour.*, Vol. 39, No. 23 (Tulsa, October 17, 1940), pp. 43–44; 1 location map.

NEW MEXICO

*"The Geology and Ore Deposits of Northeastern New Mexico," by George Townsend Harley. *New Mexico School of Mines State Bur. Mines and Mineral Resources Bull. 15* (Socorro, 1940). 104 pp., 11 figs., 3 tables, 5 pls. Paper cover. 6×9 inches. Price, $0.60.

OKLAHOMA

"Geology and Mineral Resources of Washington County, Oklahoma," by Malcolm C. Oakes. *Oklahoma Geol. Survey Bull. 62* (Norman, 1940). 208 pp., frontispiece, 19 figs., 3 pls., 18 tables.

SOUTH DAKOTA

*"Western South Dakota." First of a series in new department of "Well Logs and Field Data of Prospective Oil Areas." *Oil and Gas Jour.*, Vol. 39, No. 22 (Tulsa, October 10, 1940). 2 pp., geological map and 4 stratigraphic columns in colors.

TURKEY

*"Discovery of Petroleum at Raman," by Kemal Lokman. *Maden Tetkikve Arama Enstitüsü Mecmuasi*, Sene 5, Sayi 3/20 (Ankara, 1940), pp. 306–11; 2 maps, 6 photographs, 3 tables. In Turkish; note in English, p. 311, by Cevat E. Tasman.

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VOL. 24, NO. 12 (DECEMBER, 1940), PP. 2192-2201, 1 FIG.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

A. Nelson Sayre, Washington, D. C.
Lloyd W. Stephenson, V. T. Stringfield, Julia Gardner

FOR ASSOCIATE MEMBERSHIP

John Robert Gisburne, Tulsa, Okla.
J. B. Leiser, R. E. Shutt, W. C. Bean
Lazard Harold Kaplan, Alexandria, La.
H. V. Howe, Harold N. Fisk, Chalmer J. Roy
Thomas Hughes Philpott, Shreveport, La.
Phil K. Cochran, E. B. Hutson, Rolf Engleman
Finis Mack Samford, Kingsville, Tex.
Hal P. Bybee, Fred M. Bullard, Robert H. Cuyler
Ernest Bradley Wilson, Houston, Tex.
W. B. Milton, Jr., R. A. Stamey, Sidney A. Judson

FOR TRANSFER TO ACTIVE MEMBERSHIP

Kilburn Elie Adams, Tulsa, Okla.
J. N. Troxell, V. C. Scott, H. H. Arnold, Jr.
George Richard Carter, Midland, Tex.
J. B. Lovejoy, B. E. Thompson, H. B. Fuqua
Jackson Jefferson Flowers, Houston, Tex.
O. D. Brooks, Leroy T. Patton, G. E. Bader
George Y. McCoy, Dallas, Tex.
Ed. Shakely, L. W. MacNaughton, Arnold S. Bunte

(Continued on page 2199)

PACIFIC SECTION SEVENTEENTH ANNUAL MEETING NOVEMBER 7-8, 1940. ABSTRACTS

E. J. BARTOSH[1]
Los Angeles, California

The technical sessions of the seventeenth annual meeting of the Pacific Section of the Association were held in the theater of the Ambassador Hotel, Los Angeles, California, November 7 and 8, 1940. This part of the program included fourteen papers and addresses arranged under the direction of E. C. Edwards, of the General Petroleum Corporation, chairman of the technical program committee. The opening address was made by L. C. Snider, of New York, president of the Association, whose subject was "Association Affairs

[1] Secretary-treasurer, Pacific Section of the Association, 437 South Hill Street.

and Membership." The attendance on the first day was 300–350 persons and on the second day approximately 450 members and guests.

At the luncheon meeting on Thursday, November 7, at 12:30 P.M., in the Cocoanut Grove of the Ambassador Hotel, 145 members and their friends enjoyed the talk of A. I. Levorsen, of Tulsa, Oklahoma, chairman of the Association research committee, on affairs and plans of the committee.

The dinner dance, held in the Fiesta Room of the Ambassador on November 8, was a well attended and enjoyable affair.

At the business session, November 8, the following officers were elected for the new year: president, Frank S. Hudson of the Shell Oil Company, Inc., succeeding Albert Gregersen, of The Texas Company; secretary-treasurer E. J. Bartosh, of the Bankline Oil Company, re-elected. Nominations of candidates for Pacific Coast district representatives were made and balloting will be carried on by mail early in January, 1941. The present district representatives are H. K. Armstrong (1941), H. L. Driver (1941), and E. C. Edwards (1942).

C. W. Johnson, of the Richfield Oil Corporation, was chairman of the arrangements committee. The total registration at the meeting was 372 members and guests.

The Pacific Section of the Society of Economic Paleontologists and Mineralogists met at the Clark Hotel, Los Angeles, 6:00 P.M., November 7, for the annual election of officers, dinner, and program. Frank Tolman, of the Richfield Oil Corporation, was elected president, succeeding James M. Hamill, of The Texas Company, and W. T. Rothwell, Jr., of the Richfield Oil Corporation, was elected secretary-treasurer, succeeding Edward B. Fritz, of the Union Oil Company. The Paleontology Section was addressed by Roy M. Barnes, of the Continental Oil Company, on the subject "Exploration Activities and Results in California."

The technical program follows.

1. L. C. Snider, New York: Address by National President of The American Association of Petroleum Geologists.

2. Fredrick Romberg, Geophysical Service, Inc.: Quantitative Introduction to Gravity Prospecting (abstract).

Discussion of the principles involved and operation of a gravity meter. Comparison of gravity meter and torsion balance. Illustrations of geologic interpretation of gravity-meter data.

3. W. P. Woodring, U. S. Geological Survey, and M. N. Bramlette, University of California, Los Angeles: Late Miocene and Pliocene Stratigraphy and Paleontology of the Santa Maria District, California.

4. F. S. Hudson and G. H. White, Shell Oil Company, Inc.: Thrust Faulting and Coarse Clastics in Temblor Range, California (abstract).

In the region of Recruit Pass the Temblor Range consists of Miocene strata overlain by pre-Cretaceous crystalline rocks and Oligocene and upper Miocene sediments of the Recruit Pass thrust sheet. This thrust cover was folded with the underlying strata, though in somewhat lesser degree. The Recruit Pass fault on the southwest flank of the range dips southwestward toward, and in places is seen to be cut by, a northwest-trending vertical fault. This is believed to be the northeasternmost element of the San Andreas Rift zone, a strip 2 miles wide covered by faulted Pliocene, bounded on the south-

west by the line of recent activity that is generally called the Rift. The crystalline rocks are not native to Temblor Range but were thrust over it from a source either within, or to the southwest of, the Rift zone.

The major movement on Recruit Pass fault was certainly pre-Quarternary and perhaps as early as latest Miocene. It is suggested that movement began during Santa Margarita (upper Miocene), and that the materials of the fanglomerate lenses in Santa Margarita shale found on the northeast flank of the range came from the crystalline rocks which were thrust into the area tributary to the basin of shale deposition.

5. JOHN F. DODGE, University of Southern California, HOWARD C. PYLE, and EVERETT G. TROSTEL, Union Oil Company: The Estimation by Volumetric Methods of Recoverable Oil and Gas from Sands (abstract).

The classical formula for volumetric estimates involving factors for area, sand thickness, porosity, saturation and recovery is reviewed and the need for modification and amplification of the factors demonstrated. Individual factors are redefined in their new content and methods for their evaluation outlined. The need for consideration of both physical and economic effects in the choice of a recovery factor is emphasized. Recovery factors for oils are distinguished from those for gases for co-occurring and produced oil and gas mixtures. Applicability of volumetric reserve estimates to engineering appraisals is discussed and inherent limitations of the procedure set forth.

In conclusion the authors point out that practical accuracy in volumetric estimates of oil and gas reserves is dependent both on the accuracy and completeness of the data available and on the skill and resourcefulness of the engineer and geologist in analyzing and visualizing reservoir conditions and fitting together the fragmentary data into a compatible whole. Similarities with, and differences from, other fields within his experience should be recognized as well as the practical limitations of the factors involved, their relative importance and relative weight.

6. RICHARD H. FLEMING and M. C. SARGENT, The Scripps Institution of Oceanography: The Accumulation of Marine Diatomaceous Sediments (abstract).

Discussion of the oceanographic aspects of diatomaceous deposits with emphasis on the conditions favoring the production of large numbers of diatoms in the surface layers of the water, as well as some of the factors which may affect the deposition and preservation of their skeletal remains.

7. HERSCHEL L. DRIVER, Standard Oil Company of California: The Rôle of Foraminifera in the Oil Industry (abstract).

Data derived from foraminiferal investigations have been applied during the past 18 years as an aid in the solution of economic problems. Foraminifera and other organisms are used along with texture, hardness and color of rocks, fluid and mineral content, electric logs, and geophysical data as means of correlation. Fossils supply the sole practical means of determining the age of rocks. Micropaleontology laboratories deal with about 15,000 to a small fraction of that number of samples per month, resulting in marked variations in personnel, technique and results.

8. RICHARD W. SHERMAN, British American Oil Producing Company: Geology of the del Valle Field, Newhall District, California.

9. R. W. NORTON, Standard Oil Company of California: Interpretaton and Application of Electric Logs (abstract).

A very brief description of the resistivity and self-potential curves, explaining the various measurements which are made. The application of these measurements to geological correlations and interpretation of formation content.

10. HARRY R. JOHNSON, consultant: Geology and Gas Potentialities of Marysville Buttes (abstract).

Marysville Buttes, a strikingly isolated, nearly circular topographic feature about 10 miles in diameter, rises nearly midway across the Sacramento Valley, from a marginal elevation of less than 100 feet above sea-level to more than 2,000 feet in its craggy central part.

Geologically, the Buttes are believed unique as far as California is concerned: successive volcanic and deformational episodes have greatly disturbed Cretaceous, Eocene, Pliocene, and possibly even younger sediments in a broad peripheral zone, the outer margin of which is hidden beneath a thick mantle of volcanic ejecta originating at a central crater developed during the final phase of activity.

Gas in commercial amounts has already been developed on the south side of the Buttes in sands of Cretaceous age, and evidence indicates other favorable structural traps for gas and possibly for oil elsewhere within the marginal area of the uplift. Field studies during the past summer have thrown new light upon the Cretaceous-Eocene relationships and upon hitherto misunderstood structural conditions.

11. A. F. WOODWARD, Stanley and Stolz: Recently Discovered Deep Miocene Production in the Inglewood Oil Field (abstract).

Miocene production has been extensively developed in almost every field in the Los Angeles Basin. The fact that the Inglewood oil field was one of the principal exceptions prompted the drilling of Sentous No. 1 on the south flank of Inglewood fold by the R. R. Bush Oil Company.

The Sentous test found the top of the Miocene at about 7,350 feet and productive sands between 8,325 and 8,757 feet. The Pliocene section was normal, but thicker than expected. The upper Miocene sediments consisted principally of nodular shale, siltstone, and fine-grained silty sandstone, with some altered tuff beds and volcanic material between 8,350 and 8,425 feet. Production is coming from the lower part of upper Puente (upper Miocene).

12. W. S. OLSON, The Texas Company: Seismic Velocity Variations in the San Joaquin Valley (abstract).

Velocity data have been obtained in approximately eighty wells in the San Joaquin Valley largely due to the efforts of the Coöperative Well Velocity Surveying Group, organized in July, 1938. Analysis of these data has revealed the existence of rapid lateral changes in velocity which fit into a regional pattern. The causes of the variations are discussed, also their effect on seismic reflection mapping. Some methods for correcting reflection-survey data are considered. A considerable number of these were furnished by Cecil H. Green with well data from E. H. Vallat.

13. ROLLIN ECKIS, Richfield Oil Corporation: The Stevens Sand, Southern San Joaquin Valley, California (abstract).

The Stevens sand, first penetrated in 1936 by the Shell Oil Company's discovery well at Ten Sections oil field, is present beneath a large part of the southern San Joaquin Valley in Kern County. It has a maximum known thickness in excess of 2,000 feet, and at present is yielding commercial production from seven different structures.

It comprises the series of sands penetrated by wells in the southern part of the San Joaquin Valley, that lies below the top of a prominent cherty brown shale zone within the upper Miocene. This paper deals primarily with the distribution, character and probable origin of the sand body.

14. J. E. EATON, consultant: Ecologic Factors in Correlation (abstract).

The fact that migrating and recurring ecologic environments cause many correlations based on fossil faunas and floras to reflect homotaxial rather than time equivalencies has long been recognized. The principle involved has been applied, however, chiefly where marked differences in latitude, different provinces, or other obvious relations are apparent. There has been a tendency to tacitly imply, or to even state, that ecology can be more or less safely ignored when comparing similar faunas within a province or part of a province.

Recent research on the environments of Miocene faunas, including a unique evolutionary record of the extremely short-ranged and precise astrodapses, suggests that ecologic factors cannot be ignored even over short distances without incurring the risk of serious errors in correlation. In the Miocene of California, certain previously accepted molluscan correlations between southern and northern basins of the state are now indicated to be erroneous by as much as one natural stage. Certain previously accepted foraminiferal correlations between southern and northern basins are now indicated to be erroneous by as much as one-third of the epoch. More locally, changes in fauna due to ecology which could cause errors approximately as large have been noted in tracing a horizon three or four miles basinward from an ancient strand.

Migration, with time, of relevant temperatures and hence of certain faunal environments, from north to south and from open waters toward the strand, appears to have been the chief cause of mistaking homotaxial for time equivalencies in these Miocene correlations. Data thus far secured rather closely corroborate pioneer work by Natland.

The problem of avoiding errors arising from homotaxis is an almost infinitely vast and complicated one, because nearly all standards for comparison are relative. As a beginning, more emphasis might be placed on those supposed index fossils of relatively short range, and less on assemblages of long-range forms. More effort might be made to split species into varieties having differing ranges. In particular, it is suggested that the policy be adopted of always mentioning ecologic factors, even if only to state that such factors are presumably present but can not be evaluated.

TWENTY-SIXTH ANNUAL MEETING, HOUSTON
APRIL 2–4, 1941

Alexander Deussen, chairman of the Houston steering committee, reports satisfactory progress in the plans of his several committees for the twenty-sixth annual meeting of the Association, April 2, 3, and 4, 1941. George S. Buchanan, president of the Houston Geological Society, which is the host for the convention, is looking forward to entertaining an unusually large gathering. Since 1924, the year in which Houston first entertained the A.A.P.G. in annual meeting, the membership of the Association has more than tripled and since 1933, the second year the convention met in the Texas Port City, more

than 1,100 geologists, paleontologists, and geophysicists have been added to the membership roll, making the total 3,489 (November 30, 1940).

The Rice Hotel, headquarters for the meeting, has been remodeling its lobby and mezzanine floors, anticipating a capacity crowd during the week of March 31 to April 6. Concurrent meetings at the Rice will be held by the Society of Economic Paleontologists and Mineralogists (April 3 and 4) and the Society of Exploration Geophysicists (April 1, 2, and 3). Group and individual field trips will make use of the week-ends before and after the technical ses-

Houston Chamber of Commerce

Statue of General Sam Houston at Hermann Park, Houston. General Houston led the early Texans to victory in the struggle of Texas to obtain independence from Mexico in 1836. General Houston helped establish the new Republic of Texas, and served as its first president.

sions. The membership of the S.E.P.M. is 338 and that of the S.E.G. is 900. The three societies have a combined enrolment of approximately 4,500, after eliminating overlapping memberships. The total attendance of members, wives, and friends is expected to be in excess of 2,000. The largest A.A.P.G. registration was recorded at Oklahoma City in 1939, the total being 1,858.

Advance information shows the following preliminary personnel of the convention committees.

General committee—ALEXANDER DEUSSEN, chairman, consulting geologist, 1006 Shell Building; W. B. Heroy, L. P. Garrett, John M. Vetter, Cliff Boles, Roy L. Beckelhymer, George S. Buchanan, Marcus A. Hanna, Wallace C. Thompson.

Hotel and registration.—OLIN G. BELL, chairman, Humble Oil and Refining Company; J. A. Wheeler, W. A. Gorman, F. G. Evans.

Technical program.—D. PERRY OLCOTT, chairman, Humble Oil and Refining Company; H. B. PEACOCK, assistant chairman, representing the S.E.G., Geophysical Service Corporation, Inc.; MARCUS A. HANNA, assistant chairman, representing the S.E.P.M., Gulf Oil Corporation.

Subchairmen

Orval L. Brace 804 2d Natl. Bank Bldg. Houston	All development papers
Shirley L. Mason Stanolind Oil and Gas Co. Houston	Gulf Coast district of Texas to and including Jackson County, southern Louisiana, all of Mississippi, Alabama, and Florida
Herschel H. Cooper 1015 Milam Bldg. San Antonio, Tex.	Southwest Texas area, including approximate area of districts 1, 2, and 4 of Railroad Commission of Texas
Ronald K. DeFord Argo Oil Corporation Box 865, Midland, Tex.	West Texas Permian basin, including West Texas and southeastern New Mexico
Joseph H. Markley The Texas Company Box 1720, Fort Worth, Tex.	South Mid-Continent area, including Texas Panhandle, North Texas, East Texas, North-Central Texas, North Louisiana, South Arkansas
John G. Bartram Stanolind O. & G. Co. Box 591, Tulsa, Okla.	North Mid-Continent area, including Oklahoma, Kansas, Nebraska, Missouri
Alfred H. Bell State Geological Survey Urbana, Illinois	Central and eastern states, including Illinois, Indiana, Michigan, Kentucky, Tennessee, Ohio, Pennsylvania, West Virginia
Earl B. Noble Union Oil Co. of California Los Angeles, California	State of California
C. E. Dobbin U. S. Geological Survey Denver, Colorado	Rocky Mountain area, including northeastern New Mexico, Colorado, Utah, Wyoming, Montana

Scientific exhibits of Gulf Coast geology.—PAUL WEAVER, chairman, Gulf Oil Corporation; Lon D. Cartwright, Jr., J. Brian Eby, Walter H. Spears, F. W. Rolshausen, W. F. Calohan, W. E. Greenman.

Field trips.—J. A. CULBERTSON, chairman, Continental Oil Company; Martin M. Sheets, James K. Rogers, L. P. Teas, M. H. Steig, Wayne F. Bowman, A. G. Wolf.

ADDITIONAL APPLICATIONS APPROVED FOR PUBLICATION

(Continued from page 2192)

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Willem Fagginer-Auer, Belmont, Mass.
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James Herbert Pernell, Dallas, Tex.
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Arthur Leland Snow, San Antonio, Tex.
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Eugene McDermott, H. B. Peacock, W. R. Ransone

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Edward Arthur Frederickson, Norman, Okla.
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John C. Maher, University, La.
Eugene C. Reed, E. F. Schramm, A. L. Lugn
Ezra H. Powell, Beeville, Tex.
Stuart Mossom, S. A. Thompson, Weldon W. Hammond

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 12 (DECEMBER, 1940), PP. 2202-2204

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

WALTER K. LINK, recently with the Standard Oil Company of Louisiana, at Shreveport, Louisiana, is with the West India Oil Company, S. A., Box 5039, Ancon, Canal Zone.

J. P. MCCULLOCH has changed his connection from the Standard Oil Company of California, at San Francisco, to The Texas Company, 135 East 42d Street, New York City.

JOHN R. GISBURNE, of the Shell Oil Company, Inc., has been transferred to the headquarters office at Tulsa, Oklahoma, after several months of field work. His address is 1501 South Jamestown Avenue.

ALEX W. MCCOY, of Ponca City, Oklahoma, a past-president of the Association, has been appointed manager of the land, geological, and geophysical departments of the Deep Rock Oil Corporation, Tulsa, succeeding LUTHER H. WHITE, resigned.

FRANK BUTTRAM, independent operator, Oklahoma City, Oklahoma, is president of the Independent Petroleum Association of America. HAROLD B. FELL, of the Simpson-Fell Oil Company, Ardmore, Oklahoma, is executive vice-president.

EARL A. TRAGER, for several years chief of the naturalist division of the National Park Service, is now manager of the Washington branch of the Bell and Howell Company, 1221 G Street, N. W., Washington, D. C.

K. C. SCLATER, is first vice-president and editor of *The Petroleum Engineer*, published in Dallas, Texas.

HARVEY M. LYTEL has returned from work for the Socony-Vacuum Oil Company in Egypt and may be addressed in care of the General Petroleum Corporation of California, 2525 East Thirty-Seventh Street, Los Angeles.

CHARLES H. BEHRE, JR., of the department of geology at Northwestern University, Evanston, Illinois, recently talked on "The Mineral Industry of Europe and North Africa, Personal Impressions," before the Illinois Geological Society.

JULIAN K. PAWLEY, of the General Geophysical Company, has moved from Wooster, Ohio, to 6227 St. Claude, New Orleans, Louisiana.

S. M. ARONSON, of the Atlantic Refining Company, has moved from Dallas, Texas, to 914 Giddens-Lane Building, Shreveport, Louisiana.

GEORGE L. RICHARDS, JR., of the Shell Oil Company, Inc., has been transferred from Los Angeles, California, to San Antonio, Texas.

EMIL MONSOUR, of the Sun Oil Company, has been transferred from Tallahassee, Florida, to Dallas, Texas.

S. J. ASZKLAR, who earned the M.A. degree at the University of Wisconsin in 1939, is employed by the Gulf Research and Development Company, Houston, Texas.

E. FLOYD MILLER, geologist of the Oliphant Oil Corporation, recently addressed the Shreveport, Louisiana, Geological Society, on "The Cotton Valley Field." Miller is past-president of the Shreveport Society.

GEORGE R. DOWNS has resigned from the Superior Petroleum Company at Shelby, Montana, to become geologist for the Carter Oil Company at Bismarck, North Dakota.

PHILIP D. GULLY, consulting geologist, has moved his office from Beeville, Texas, to the Milam Building, San Antonio, Texas.

ALDEN STUART DONNELLY, geologist with the Honolulu Oil Corporation at Midland, Texas, is secretary-treasurer of the North Basin Pools Engineering Committee, succeeding R. R. PORTERFIELD of the Devonian Oil Company.

GAYLE SCOTT, professor of geology at Texas Christian University, addressed the Fort Worth Geological Society, October 21, on "The Correlation and Relationship of the Texas Midway."

E. R. BROCKWAY, of the Devonian Oil Company, is situated at Fort Worth, Texas.

M. M. SLOTNICK, of the geophysical department of the Humble Oil and Refining Company, recently addressed the Houston Section of the American Institute of Electrical Engineers on "Seismic and Gravity Methods in Petroleum Geophysics."

CHARLES P. MCGAHA, vice-president of the Fain-McGaha Oil Corporation, Wichita Falls, Texas, is president of the National Stripper Well Association.

M. D. MAUCK, of the Pure Oil Company, has been transferred from Olney, Illinois, to Tulsa, Oklahoma.

SAMUEL W. WELLS is with the Mohican Drilling Company, Ada, Oklahoma.

The Illinois Mineral Industries Conference at Urbana-Champaign, November 14, 15, and 16, sponsored by the Illinois Geological Survey, the Engineering Experiment Station of the University of Illinois, and the Illinois Mineral Industries Committee, included in its program the following Devonian symposium and a group of papers on oil and gas.

J. MARVIN WELLER, geologist, Illinois Geological Survey: The Devonian System in Southern Illinois.

CAREY CRONEIS, associate professor of geology, University of Chicago: The Devonian System in Southeastern Missouri.

HUGH D. MISER, geologist, U. S. Geological Survey: The Devonian System in Arkansas and Oklahoma.

KENDALL E. BORN, assistant geologist, Tennessee Geological Survey: The Devonian System in Western Tennessee.

LOUISE B. FREEMAN, assistant geologist, Kentucky Geological Survey: The Subsurface Stratigraphy of the Devonian System in Western Kentucky.

A. H. SUTTON, associate professor of geology, University of Illinois: The Devonian System in Indiana.
E. B. BRANSON, head, department of geology, University of Missouri: Devonian System in Northern Missouri.
H. S. MCQUEEN, assistant State geologist, Missouri Geological Survey: Cross Section of the Devonian Formations in the Forest City Basin.
M. S. STAINBROOK, professor of geology, Texas Technological College (paper presented by A. C. TROWBRIDGE, State geologist of Iowa): The Devonian System in Iowa.
L. E. WORKMAN, geologist, Illinois Geological Survey: Subsurface Stratigraphy of the Devonian in Illinois.
G. W. CAYLOR, geologist, Shell Oil Company, Inc.: Devonian Rocks in the Centralia Area.
L. A. MYLIUS, consulting geologist, Bell Brothers: Some Practical Applications of Geology in Illinois Rotary Drilling.
BART DELAAT, division engineer, Pure Oil Company: Recent Advances in Illinois Drilling.
D. H. DUKE, petroleum engineer, Shell Oil Company, Inc.: Production Engineering.
W. F. ETTING, petroleum engineer, Carter Oil Company: The Gas Injection Project at Loudon.
W. H. VOSKUIL, mineral economist, Illinois Geological Survey: Oil in International Relations.

E. W. KRAMPERT, consulting geologist of Casper, has been appointed State geologist of Wyoming, succeeding S. H. KNIGHT, resigned.

ACUS EDWARDS, who received the degree of Master of Arts, majoring in geology, from the University of Wyoming last June, has been employed in the exploration department of the Shell Oil Company, Inc., Tulsa.

E. W. KIMBALL, of the geological department of the Continental Oil Company, has moved from Hobbs, New Mexico, to Wichita Falls, Texas.

THOMAS M. PRETTYMAN, of the West Texas Oil and Royalty Corporation, died at Fort Worth, Texas, November 2.

The Shreveport Geological Society, Shreveport, Louisiana, has elected the following officers: president, WARREN B. WEEKS, Phillips Petroleum Company; vice-president, WELDON E. CARTWRIGHT, Tide Water Associated Oil Company; secretary-treasurer, S. C. GIESEY, Stanolind Oil and Gas Company; historian, R. B. TOTTEN, Phillips Petroleum Company.

The North Texas Geological Society, Wichita Falls, Texas, has elected new officers: president, J. R. SEITZ, of Seitz, Comegys, and Seitz; vice-president, J. J. RUSSELL, JR., Sinclair Prairie Oil Company; secretary-treasurer, J. M. CLARK, Tide Water Associated Oil Company.

Sigma Gamma Epsilon held its annual symposium at the University of Oklahoma, Norman, December 7. The topic was "Major Divisions of the Pennsylvanian of the Mid-Continent."

CECIL HAGEN, consulting geologist, Houston, Texas, has returned to his office after a business trip to Ecuador.

The Geological Society of America extends a special invitation to the members of the American Association of Petroleum Geologists and affiliated societies to attend and participate in the 53d annual meeting, the University of Texas, Texas Union Building, Austin, Texas, December 26–28.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 12 (DECEMBER, 1940), PP. 2205-2232

INDEX OF VOLUME 24 (1940)

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of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

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of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

VOLUME 24

JANUARY—DECEMBER 1940

PART I

PAGES 1-1156

ASSOCIATION HEADQUARTERS
BOX 979, TULSA, OKLAHOMA

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Wichita, Kansas

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So. Permian Basin
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CONTENTS OF VOLUME 24 (1940)

PART I

NUMBER 1 (JANUARY)

NUMBER 2 (FEBRUARY)

NUMBER 3 (MARCH)

NUMBER 4 (APRIL)

NUMBER 5 (MAY)

NUMBER 6 (JUNE)

ERRATA

Pages 50 and 63: Docum should be *Dockum.*
Page 145, table: Carizzo should be *Carrizo.*
Page 400, paragraph 2 from end, and center heading: Eleventh annual meeting should be *Tenth* annual meeting.
Page 802, footnote 11, line 4: Broad head formation should be *Brodhead formation.*
Page 940, line 8: Isaiah Bowen should be *Norman L. Bowen.*
Page 1103, Figure 2: two black spots, due to mechanical imperfection, erroneously appear in the southeast (lower right) corner of the map, one below the word "Hartville," the other below the symbol for "gas field" in the "explanation" column.

BULLETIN

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JANUARY—DECEMBER 1940

PART II

PAGES 1157-2232

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NUMBER 7 (JULY)

NUMBER 8 (AUGUST)

NUMBER 9 (SEPTEMBER)

NUMBER 10 (OCTOBER)

NUMBER 11 (NOVEMBER)

NUMBER 12 (DECEMBER)

ERRATA

Page 1699, last line: El Renos should be *El Reno.*
Page 2006, Abstract, line 7: 20,0000 feet should be *20,000 feet.*

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2nd Vice-President - - - - - - Ninetta Davis
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Atlantic Refining Company

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Amerada Petroleum Corporation

Associate Editor - - - - - - Hiram J. Tandy
Route 7

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Meetings: Monthly and by call.
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel.

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Union Oil Company of California
1134 Commercial Building

Treasurer - - - - - - - - - Dugald Gordon
Brokaw, Dixon, and McKee, Gulf Building

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Tide Water Associated Oil Company
924 Hamilton Building

Luncheons and evening programs will be announced.

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Stanolind Oil and Gas Company, San Antonio

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1742 Milam Building, San Antonio

Executive Committee - - - - - - L. W. Storm

Meetings: Third Friday of each month alternately in San Antonio and Corpus Christi. Luncheon every Monday noon at Milam Cafeteria, San Antonio, and at Plaza Hotel, Corpus Christi.

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Vice-President - - - - William A. Bramlette
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Secretary-Treasurer - - - - - - Travis Parker
Univ. Texas, Dept. of Geology

Meetings: Every third Friday at 8:00 P.M. at the University of Texas, Geology Building 14.

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Standard Oil Company of Texas, Box 1660

Vice-President - - - - - - - - Dana M. Secor
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Meetings will be announced

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Owens, Libbey-Owens Gas Department
Box 1375, Charleston, W.Va.

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

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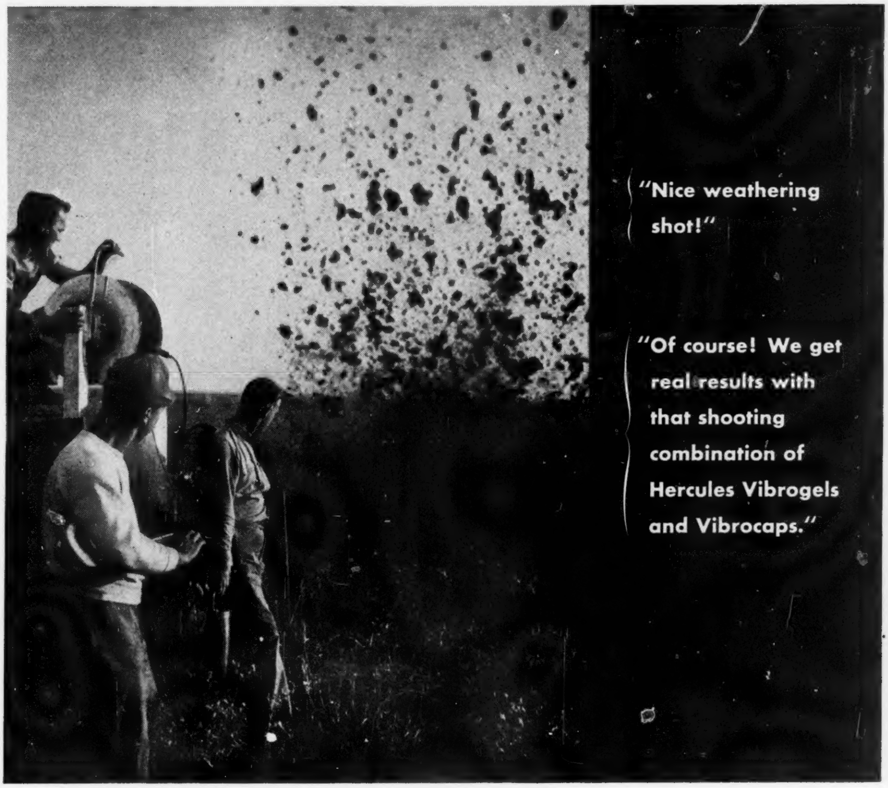
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